

WARNING! DANGER! PELIGRO! PERICOLO!

GEFAHR! PERIGO! κίνδυνος! опасность!

Hydrogen is dangerous to work with because it is **EXTREMELY** flammable.

Great caution must be used in attempting to utilize any form of hydrogen conversion/technology. The author cannot be held liable for any actions that you undertake, or possible resultant damage that you could suffer, by use of this public domain technology.

Hydrogen is extremely dangerous because of its flammability.

Remember the Hindenburg!



# Make Your Car Run On Water

First Edition

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Save the Earth, and your cash!

Stop paying fraudulently high gas prices!

Patents you can use, without having to pay any royalties, to  
stop using petroleum for your car, truck, or home.

## PREFACE

The solution to Peak Oil, Global Warming, and repairing the American and Global Economies is here, that at the same time can heal the environment of our injured planet, advancing conservation concerns.

I have compiled this volume as solutions for getting off the grid, and off of petroleum. Saving the environment can be done while saving your money. I want to make as many people aware of these technologies as possible to advance the grass roots effort that will prevent global ecological disaster.

This volume addresses the issues of power generation in a manner and means applicable to everyone, with a particular emphasis on power systems for the home, and for converting their automobiles to run on water/hydrogen.

"Hydrogen Power Systems" is uniquely written for the average person who is interested in utilizing alternative fuels, namely hydrogen. This particular volume has as its focus the revealing of public domain technology to convert your standard automobile to a water/hydrogen fueled vehicle. Excerpts below:

"A mechanism allows for a simple gasoline engine to be converted to run using hydrogen as a fuel by the introduction of a pulse of hydrogen during the intake stroke."

"The automobile engine is a standard version of those used in modern automobiles but the fuel used to power the engine is an air and hydrogen mixture."

"A combustion engine which uses in combination oxygen and an excess of hydrogen as fuel has a substantially closed exhaust system which recirculates the gaseous part of the exhaust through the engine and expels only water."

This volume gives humanity the ability to create and harness electricity and clean combustion engine power for themselves without burning fossil fuels. Greenhouse gas emissions can be eliminated. As Peak Oil approaches, gasoline prices continue to soar to new heights and the world economy shudders. The technology to completely eliminate this crisis exists here and now, and has existed since the 1930's.

By actively promoting this technology, we can eliminate toxic emissions, minimize our carbon footprint, and increase productivity with new green jobs. The proof is in the patents, 70 years of environmentally friendly technology that is now available to us all.

The solution to stabilizing the global economy is here.  
The ability to convert your car to run on water/hydrogen is here.  
The ability to get your home off the power grid is here.  
This technology is public domain, available to all.  
Spread the word. The technology is here.

And you will find that the bulk of the patents that make this craft a reality have gone into the Public Domain; they are YOUR property and your BIRTHRIGHT. There is no one stopping you from making the change.

*"The reason why so little is done, is generally because so little is attempted."*  
-Samuel Smiles

Luke Fortune is a certified paralegal that began investigating alternative energy systems back in 1992. This book is over 400 pages in length. This book's contents are complete patents that anyone can use free of charge. The book is designed to simplify the understanding of hydrogen engine systems for the comprehension of the average person.

The author in no way takes responsibility for what you do with the information contained in these patents. Any replication of inventions read about in these pages is done at your own risk. BE CAREFUL.



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## HYDROGEN SYSTEMS

This particular Volume was written with the particular slant and emphasis that the average reader should be able to apply this knowledge to his or her own automotive vehicle.

This particular technology can be applied to your own car or truck. I have started this Volume with the patent "Conversion Device Enabling A Gasoline Engine To Be Fueled With Hydrogen," and included hydrogen burning engine patents that go back as far as the 1930's.

Many public domain patents are included to aid the reader in his or her quest to move away from fossil fuels. And what better solution than tap water! Cheap, readily available, and no atmospheric pollution concerns!

The question has been raised about the claims of the "ten thousand mile per gallon gasoline engine." Does it exist? If so, then why hasn't it been implemented?

I quote directly from Shell.com's 'Ecomarathon':

[http://www.shell.com/home/content/uk-en/society\\_environment/eco\\_marathon/about/about\\_eco\\_marathon\\_0204.html](http://www.shell.com/home/content/uk-en/society_environment/eco_marathon/about/about_eco_marathon_0204.html)

(If this page doesn't come up, make sure that your web browser didn't drop the letter "l" at the end of the address bar in your browser window. Should be ".html" not ".htm")

*"The history of the Shell Eco-Marathon stretches back over 50 years. It originated at Shell's research lab in Illinois, US, with friendly wagers between fellow scientists to see who could get the most miles per gallon from their vehicles. From these humble origins, where the winner scarcely achieved 50MPG, more organized competitions evolved.*

*In 1977, Shell organized the first competition at Mallory Park essentially for student teams. In 1978 the competition grew further and an open class was introduced.*

*Over the years, the fuel economy record has been rapidly improved. The most recent record was set at the 2003 event by team Microjoule from St Sebastien/Loire in France. They achieved a fuel consumption figure of **10,705 miles per gallon** - beating the previous record set by the same team in 2001 by nearly 500 mpg."*

So why doesn't your car burn fuel that efficiently?

Why are you paying so much for gasoline these days?

**United States Patent** [19]

BEST AVAILABLE COPY

[11] **3,897,757****Abello**[45] **Aug. 5, 1975**

[54] **CONVERSION DEVICE ENABLING A  
GASOLINE ENGINE TO BE FUELED WITH  
HYDROGEN**

2,937,634	5/1960	Kelseaux .....	123/DIG. 12
3,572,297	3/1971	Murray .....	123/1 A
3,665,896	5/1972	Crehore .....	123/1 A
3,665,896	5/1972	Crehore .....	123/DIG. 12

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[73] Assignee: **Canadian Jesuit Missions**, Toronto,  
Canada

[22] Filed: **Feb. 16, 1973**

[21] Appl. No.: **332,815**

[30] **Foreign Application Priority Data**

Oct. 20, 1972 Canada ..... 154350

[52] U.S. Cl. .... 123/1 A; 123/DIG. 12

[51] Int. Cl. .... F02b 75/12

[58] Field of Search ..... 123/120, 121, 1 A, 129,  
123/139 H, 27 GE, 90.1, DIG. 12

[56] **References Cited**

**UNITED STATES PATENTS**

1,340,444	5/1920	Hayes .....	123/129
2,852,013	9/1958	Dauids .....	123/120

**FOREIGN PATENTS OR APPLICATIONS**

865,413	4/1961	United Kingdom .....	123/120
831,429	9/1938	France .....	123/DIG. 12

*Primary Examiner*—Charles J. Myhre

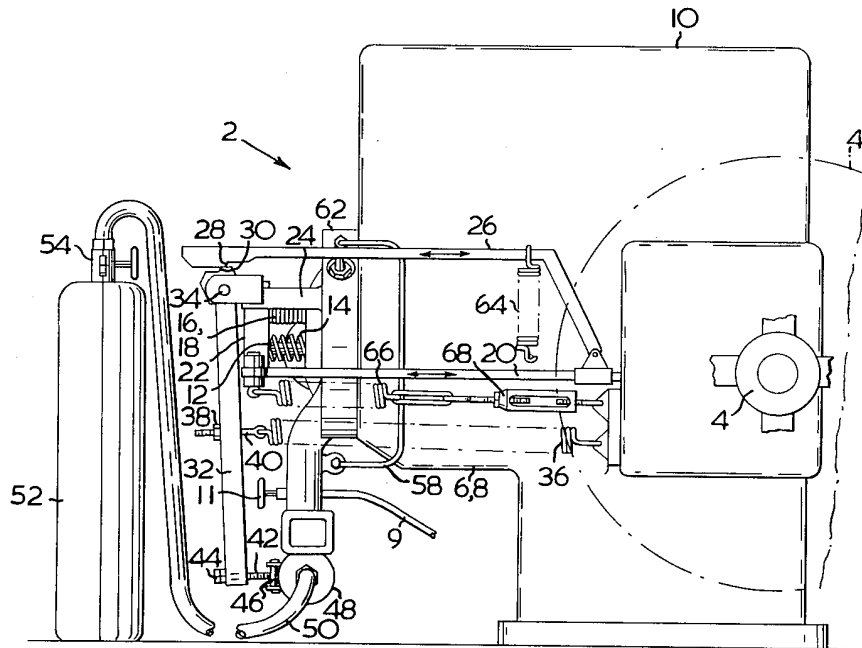
*Assistant Examiner*—R. H. Lazarus

*Attorney, Agent, or Firm*—Spencer & Kaye

[57] **ABSTRACT**

A mechanism allows a simple gasoline engine to be converted to run using hydrogen as a fuel by the introduction of a pulse of hydrogen during the intake stroke. The mechanism is such that an engine may use either fuel at will but preferably simple changes to the cylinder head allow an engine to be converted into a high compression engine using hydrogen alone because of the greater efficiency.

**7 Claims, 6 Drawing Figures**



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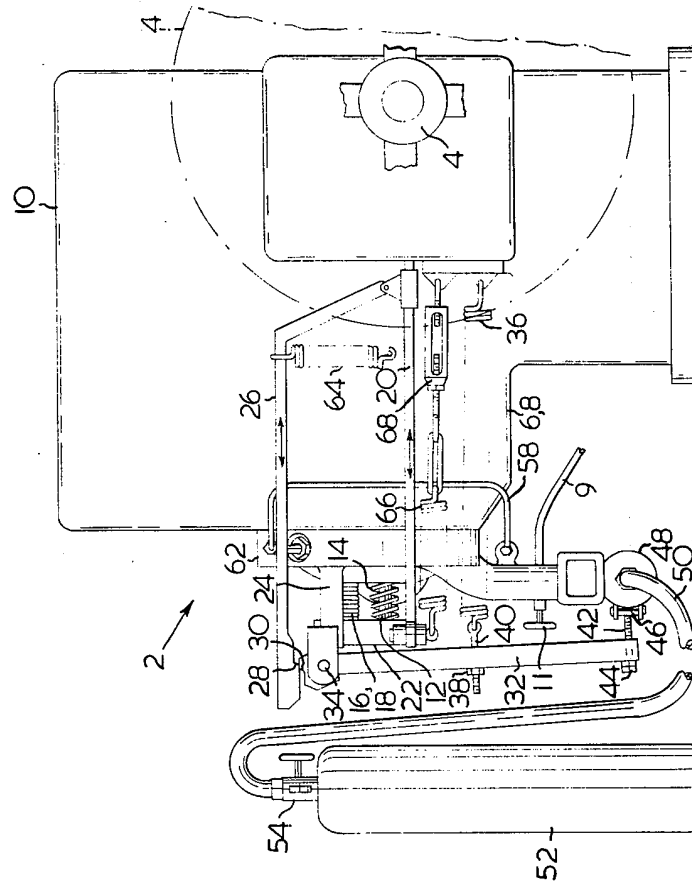


FIG. 1

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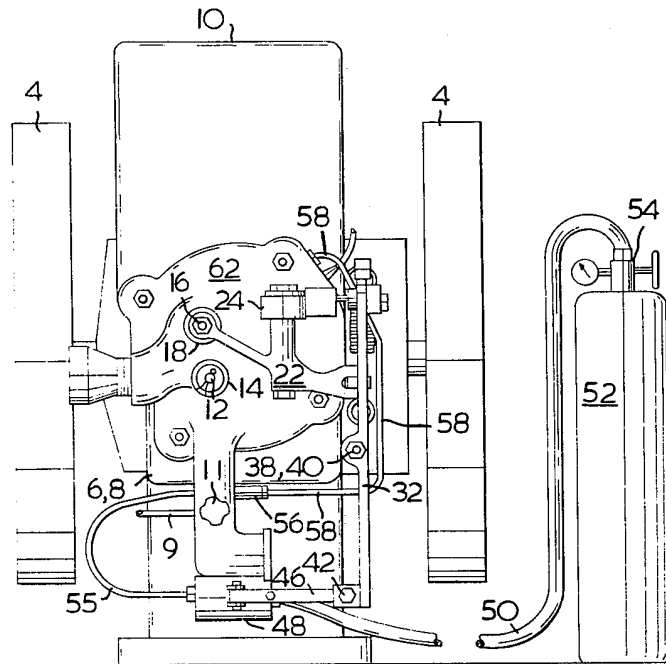


FIG. 2

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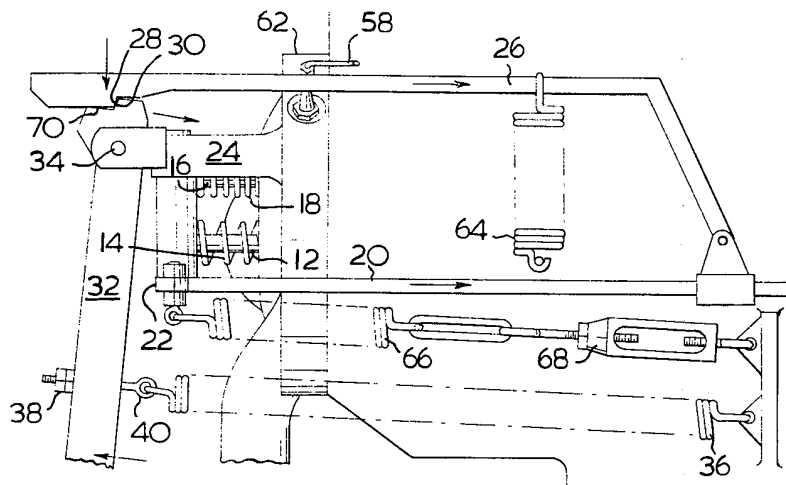


FIG. 3A

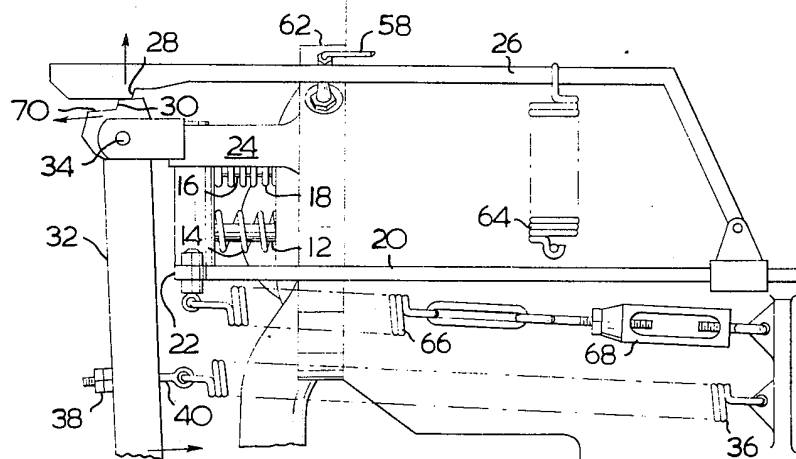


FIG. 3B

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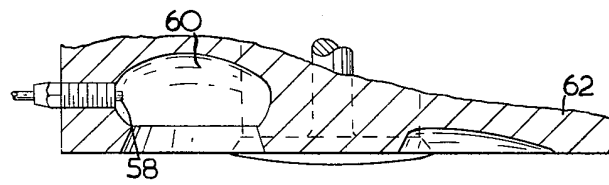


FIG. 4

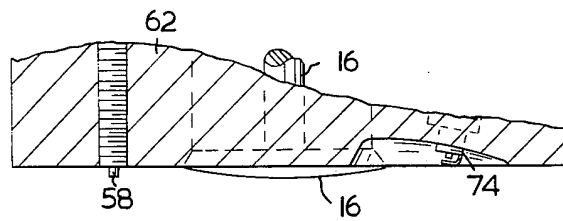


FIG. 5



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## CONVERSION DEVICE ENABLING A GASOLINE ENGINE TO BE FUELED WITH HYDROGEN

This invention relates to gasoline engines, and in particular to stationary engines. Such engines are used on outlying farms for pumping water, generating electricity and like tasks, and are usually of the four stroke, single cylinder type.

It is well known that such engines have disadvantages although their use is exceedingly widespread. For instance, the hydrocarbon nature of gasoline fuel requires that such engines be decarbonized regularly; due also to the hydrocarbon fuel the exhaust is noxious - that is, the carbon monoxide which is inevitably generated can build up to lethal concentrations in enclosed spaces; thus, exhaust pipework is needed if the engine is to be serviced while running, as a weatherproof shelter is required for ignition protection. Miscellaneous hydrocarbons in the exhaust also pollute the atmosphere, as is also well known.

Many proposals have been made to use hydrogen as a fuel, but these have required such elaborate modifications as to be virtually specially built engines, typical examples being U.S. Pats. Nos. 2,183,674; 3,471,274 and 3,572,297.

Such prior art so deeply underscores the likelihood of detonation, and the difficulty of efficient mixing that the possibility of using hydrogen as fuel in a simple engine would seem to be remote.

An object of this invention is to solve these problems by injecting a charge of unmixed hydrogen during the intake stroke. This not only ensures good mixing and inhibits detonation and preignition but also allows a simple conversion from a gasoline engine.

A more limited object of this invention is to provide a dual fuel engine - that is, one that will run on either hydrogen or gasoline.

The invention will be more easily understood after reading the following disclosure and referring to the drawings which illustrate, by way of example, an engine which incorporates an embodiment of the invention.

FIG. 1 is a side elevation of a typical horizontal one cylinder engine modified according to the teachings of the invention;

FIG. 2 is a front end view of the engine looking on the cylinder head;

FIGS. 3a and 3b are an enlarged view of a portion of FIG. 1 with the mechanism in two different positions;

FIG. 4 is a scrap section view of the cylinder head;

FIG. 5 is the cylinder head of an alternative embodiment.

In these Figures the usual components of such an engine 2 will be easily identified. Flywheel 4 is driven by a crank and piston, not shown, because the cylinder is surrounded by an integral crank case and cylinder jacket 6, 8. A header tank 10 holds a reservoir of cooling water for the cylinder. The engine is actually a John Deere, type "E" 1½ horsepower gasoline engine, but the conversion to be described below can be carried out on any similar engine. For this reason details of standard fittings, such as the ignition, the simple carburetor, manual choke and the like, will be omitted from the description. However, the gasoline line 9 with the carburetor needle valve handwheel adjuster 11 have been numbered for easy identification.

In this engine the inlet valve 12 has a light spring 14 to bias it shut, but does not have an operating rod and

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is drawn open by suction on the inlet stroke. The exhaust valve 16 has a fairly heavy spring 18 to keep it tightly shut and is operated by a push rod 20 through a rocker arm 22 mounted on bracket 24. The push rod is driven by a cam through a 2-to-1 reduction gear from the crankshaft on which flywheel 4 is mounted.

Turning to the modification, an operating arm 26 is pivotally mounted on the push rod 20. This arm has a latch 28 on it which engages catch 30 on the end of trigger arm 32. This trigger arm is mounted on shaft 34 which fits into a bracket bolted to the rocker arm mounting bracket 24.

The trigger arm 32 is functionally a light hammer with a predetermined impulse given to it by a tensioning trigger spring 36. The setting of this spring can be adjusted to vary the impulse by adjustment nut 38 on eyebolt 40, and is normally such that the impulses resemble tapping rather than repeated hammer blows.

A striker bolt 42, with an adjustable nut 44, is located near the end of the trigger arm 32 and when the latch 28 releases the trigger arm the striker taps a pivotally mounted metering valve depression arm 46, momentarily depressing it to operate as by a tapping impulse, a spring loaded metering valve 48. Trigger arm 32 strikes the valve depression arm 46 with a force which depends only on the tension of spring 36 and its own mass and therefore the impulse which it produces for opening the valve is independent of the engine speed. In this way, the valve is opened for a brief period which is substantially independent of the engine speed.

This metering valve is fed by a line 50 from hydrogen bottle 52, or any other suitable supply of pressurized hydrogen gas. A pressure regulator 54 is set to 120 psi so that a regulated hydrogen pressure is established at the metering valve 48. When this valve is depressed momentarily, by reason of the impulse behind striker bolt 42, a burst of hydrogen passes through line 55, non-return valve 56 and line 58, which is a copper tube, directly into the combustion chamber 60 of the cylinder head 62, see FIG. 4.

The basic operation of the engine will now be understood. When running on hydrogen is desired the gasoline supply is turned off and the hydrogen supply is turned on. Preferably the spark is retarded somewhat, for optimum operation on hydrogen. When reverting to gasoline the spark should be advanced, that is timed in accordance with the spark timing mark on the engine flywheel.

When the engine is cranked to start it, the first movement of the exhaust valve push rod 20 towards the crankshaft of flywheel 4 draws operating arm 26 with the push rod and the latch 28 of the operating arm 26 engages catch 30 on the end of trigger arm 32 and is held in place by spring 64; this position is seen at FIG. 3a.

To incorporate the invention in this particular engine, it happens that another spring 66 is needed with a turnbuckle 68 to adjust it. The reason is that the exhaust valve push rod 20 also operates the igniter by further travel after the exhaust valve itself has closed, and the torsional spring (not shown to avoid confusion - it fits round about the circular bearing portion of rocker arm 22) is not strong enough to overcome the loading of tensioning trigger spring 36. Although this spring 36 is quite light - it only has to accelerate the trigger arm to provide a tapping type of impulse - it acts at such a mechanical advantage that it can hold the

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push rod 20 off from following the operating cam surface fully; although it is not strong enough to hold the exhaust valve open, it can and does prevent the lighter torsion spring from urging the push rod further to operate the igniter (also omitted for clarity).

As the exhaust valve push rod 20 moves towards the crankshaft of flywheel 4, the elbow 70 of the trigger arm catch 30 pushes the latch 28 off the catch and the trigger spring 36 accelerates the trigger arm so that bolt 42 taps the metering valve depression arm 46 when the inlet stroke has begun and the burst of hydrogen actually enters the cylinder at about 40° after TDC. This position is shown in FIG. 3b. It will be understood that triggering the tapping impulse by the exhaust valve push rod with its continuing travel beyond exhaust valve closure allows a range of timing to be achieved.

It may be necessary to raise or lower the regulator pressure to ensure that the mixture is neither too rich nor too lean; the trigger arm spring 36 is also provided with an adjustable feature so that the impulse can be varied, and to some extent these represent alternative adjustment of mixture strength. The igniter adjustment is, of course, independent of mixture strength, and depends upon which fuel the engine is using.

The above describes a dual fuel type of engine - in the sense that it can use both types of fuel. However, in another high compression embodiment the engine, although only able to use hydrogen, has a greater fuel efficiency by the substitution of a high compression head. By high compression a ratio higher than 12 to 1 is meant and a suitable ratio has been found to be 13:1. This is achieved by removing the igniter (not shown) and then filling in the combustion chamber 60. Instead of the igniter which functions as both a spark plug and breaker points, spark plug 74 was provided and the original magneto was replaced by a magneto which contained breaker points. The low compression head and the high compression modification are illustrated in FIGS. 4 and 5.

Other mechanical adjustments were made which do not concern the invention directly; for instance, a liner was inserted to reduce the displacement. It was considered that raising the compression ratio from the original 4:1 to 13:1 without other modification would merely invite premature failure of a connecting rod, main bearings or crankshaft which had been designed for the lesser duty. Moreover the 13:1 ratio does not represent the thermodynamic limit as a few tests indicated that the hydrogen did not ignite spontaneously even at a 16:1 ratio in contrast with the prior art teachings.

Thus, while there has been shown and described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be

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made therein without departing from the invention as defined by the appended claims.

I claim:

1. A positive displacement internal combustion engine adapted to use hydrogen gas comprising:
  - means for controlling the admission of air to a combustion space thereby defining an air intake stroke;
  - a hydrogen supply means;
  - means for connecting said hydrogen supply to said combustion space;
  - means for predetermining a time during the air intake stroke;
  - a normally closed valve means in said hydrogen supply connecting means;
  - means for opening said valve means for a brief period which is substantially independent of the engine speed; and
  - means connecting said time predetermining means to said valve opening means whereby a pulse of hydrogen is produced and conveyed to said combustion space, at a predetermined time during the air intake stroke.

2. An engine as claimed in claim 1 wherein the compression ratio is low enough to allow gasoline to be used as an alternative fuel.

3. An engine as claimed in claim 1 wherein the compression ratio is high enough to increase cycle efficiency above that attainable in a gasoline fueled engine.

4. An engine as claimed in claim 1 wherein said valve means comprises a spring loaded plunger operated metering valve and said valve opening means is adapted to deliver an impulsive blow to the plunger of the valve means.

5. An engine as claimed in claim 1, wherein said engine comprises an exhaust valve and operating means therefor, and wherein the means for predetermining a time during the intake stroke comprises a means connected to the exhaust valve operating means, whereby production of a pulse of hydrogen is initiated by the return stroke of said exhaust valve operating means.

6. An engine as claimed in claim 1 wherein said engine comprises an exhaust valve and operating means therefor, and wherein said valve means comprises a spring loaded plunger operated metering valve, and said valve opening means comprises a trigger arm having a catch and a latch means connected to the exhaust valve operating means, said latch means being adapted to engage the trigger arm catch as the exhaust valve operating means undergoes a return stroke, whereby the production of a pulse of hydrogen gas is initiated.

7. An engine as claimed in claim 6 wherein an elbow portion of the trigger arm forms a releasing means for releasing the catch.

\* \* \* \* \*

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(51) INT CL<sup>5</sup>

**F02M 21/02, B60K 15/10**

(52) UK CL (Edition M)

**B7H HDY H716 H742**  
**F1B B2L1A**

(56) Documents Cited

**GB 2250490 A GB 1447614 A US 3980053 A**

(58) Field of Search

**UK CL (Edition K) B7H HDY**  
**INT CL<sup>5</sup> B60K 15/10, F02B 47/06, F02M 21/02**  
**ONLINE DATABASE: WPI**

(54) **Automobile powered by electrolysis of water.**

(57) The automobile engine is a standard version of those used in modern automobiles but the fuel used to power the engine is an air and hydrogen mixture. The hydrogen constituent of the fuel supply is obtained by electrolysis of water using the spare or excess electric current supplied by the automobile's conventional generator (10). The engine of the car is initially started by the car battery (1) electrical supply which is used to rotate the generator (10) and so the crank shaft (6) until the engine starts to run on the hydrogen and air fuel supply. The engine is kept running from the supply of hydrogen from a reservoir (2) which is supplied from the electrolysis chamber (4). Air from inlet (11) is mixed with the hydrogen at the inlet manifold (7).

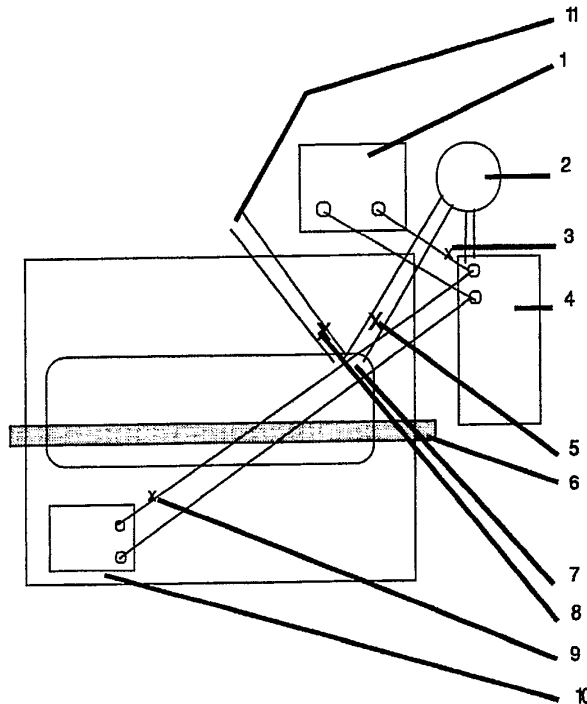


Figure 1

GB 2 269 569 A

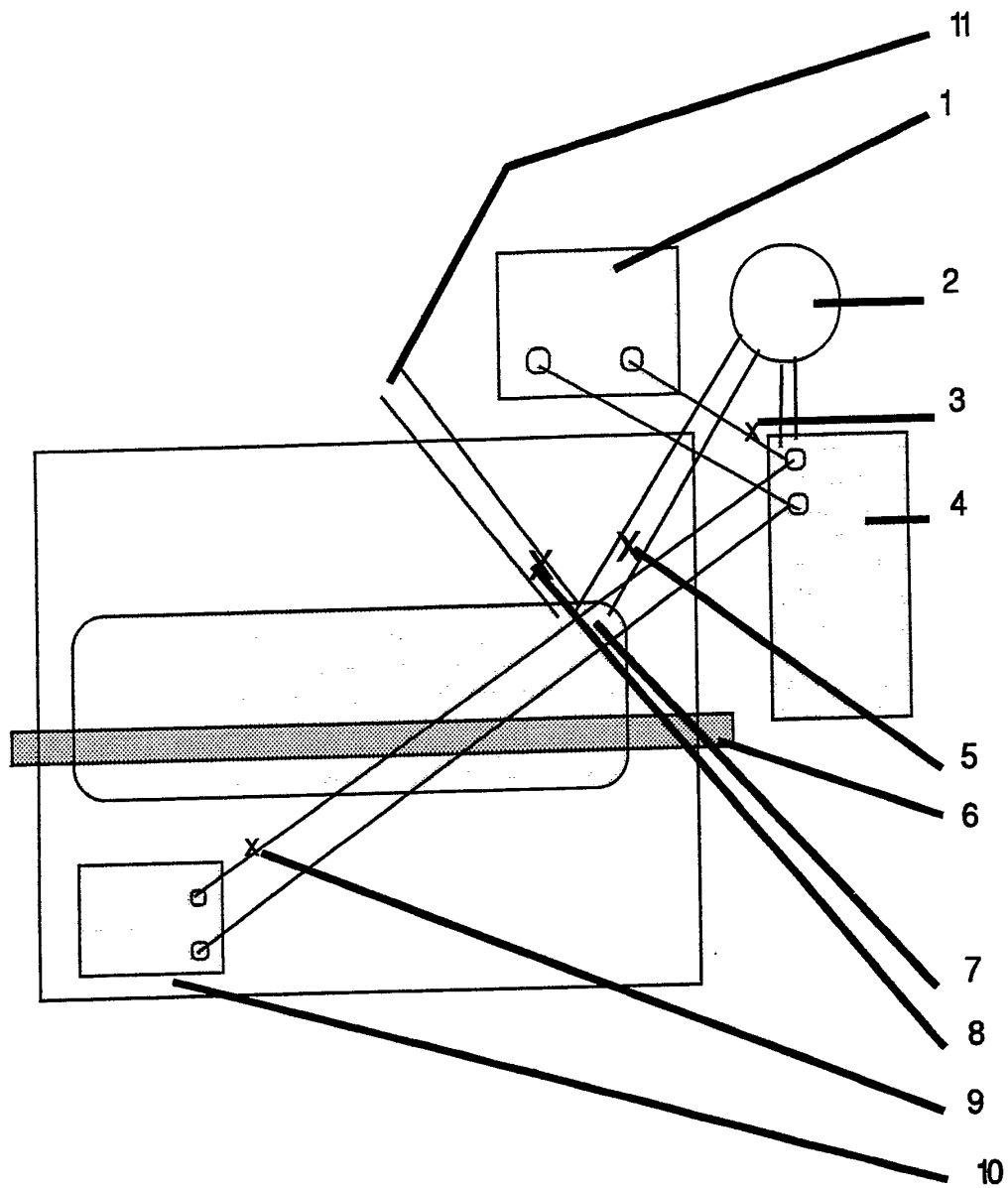


Figure 1

## Electrolysed Water to power an automobile

The principle is that an electrical power source is used to electrolyse water into its constituent parts, hydrogen and oxygen gas. The hydrogen gas is fed into a reservoir. The reservoir is connected to the engine of the automobile after passing through a regulator valve. The regulator valve, 5, is connected to the accelerator pedal as it is in a conventional car. The further it is pressed down the more hydrogen gas is allowed into the input manifold of the engine. This allows the engine to burn a larger amount of hydrogen mixed with the oxygen in air. The engine is a standard automobile engine only it no longer runs on a petrol and air mixture which is exploded in the engines cylinders but instead it runs on an hydrogen and air mixture.

Figure 1 shows the block outline of the modified fuel system of an automobile's engine system. The standard car battery is 1. This is used during the initial stages of starting the car's engine to both electrolyse the fuel supply water, 4, and to rotate the engine's crankshaft 6. Once the engine is running on the hydrogen and air mixture, 7, the car's electrical power generator, 10, supplies a recharging current to the car battery, 1, and additional power to the electrolysis chamber 4. The current from the generator is passed into the electrolysis chamber, 4, through an electrical regulator, 9, and also through another electrical regulator, 3, to the car's battery. The electrical regulator, 3, is usually present in modern automobiles. The other electrical regulator, 9, is needed in addition to control the flow of current into the electrolysis chamber 4. The air inlet, 11, is arranged so that air is sucked into the engine's input manifold through a one way valve, 8. This is so the air is mixed with the hydrogen only at the last stage in the fuel pipe, 7, at the input manifold, 7. The hydrogen supply is similarly isolated by a one way valve, 5, from the input manifold, 7. The hydrogen gas is drawn from a reservoir, 2, which is continuously kept with a surplus of hydrogen gas by the electrolysis unit, 4.

The fuel is drawn into the combustion chambers of the engine in an identical manner to a standard petrol engine and exploded at the correct moment to drive the piston head which drives the drive shaft. The moment when combustion is made to happen in the engine may be slightly different to an engine that runs on a petrol and air fuel source.

As the fuel source is hydrogen mixed with air, on combustion it results in a cleaner by-product, namely water. So, the engine is a more environmentally cleaner system.

To summarise, the automobile engine is a standard version of those used in modern automobiles. Only the fuel used to power the engine is an air and hydrogen mixture. The hydrogen constituent of the fuel supply is obtained by electrolysis of water. The water is electrolysed by using the spare or excess electrical current supplied by the automobile's conventional generator. The engine of the car is initially started by the car battery electrical supply which is used to rotate the generator and so the crank shaft until the engine starts to run on the hydrogen and air fuel supply.

## CLAIMS

1        An automobile and engine comprising of an electrolysis unit, an automobile battery and an electrical power generator which also doubles as a motor.

2        An electrolytic process as described in Claim 1 connected into the fuel inlet pipe of a modern automobile in the place of a petrol fuel supply.

3        The electrolysis unit as mentioned in Claims 1 and 2 provides a supply of hydrogen gas which when mixed with air is exploded in the automobile's cylinders to provide motive power.

4        The hydrogen gas supply is derived by electrolysing a tank of water by applying a direct current electrical supply to electrodes in the tank of water. The electrical current is obtained from a battery and the automobile's electrical generator.

**Patents Act 1977****Examiner's report to the Comptroller under  
Section 17 (The Search Report)**

Application number

GB 9217003.4

**Relevant Technical fields**(i) UK CI (Edition <sup>K</sup>) B7H (HDY)(ii) Int CI (Edition <sup>5</sup>) B60K 15/10; F02B 47/06;  
F02M 21/02**Search Examiner**

J L TWIN

**Databases (see over)**

(i) UK Patent Office

(ii) ONLINE DATABASE: WPI

**Date of Search**

2 OCTOBER 1992

Documents considered relevant following a search in respect of claims

1

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2250490 (HOME & GENERAL)	1
X	GB 1447614 (BLUE & WOOD)	1-4
X	US 3980053 (HORVATH)	1

Category	Identity of document and relevant passages	Relevant to claim(s)
Luke Fortune	Make Your Car Run On Water	

### Categories of documents

**X:** Document indicating lack of novelty or of inventive step.

**Y:** Document indicating lack of inventive step if combined with one or more other documents of the same category.

**A:** Document indicating technological background and/or state of the art.

**P:** Document published on or after the declared priority date but before the filing date of the present application.

**E:** Patent document published on or after, but with priority date earlier than, the filing date of the present application.

**&:** Member of the same patent family, corresponding document.

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# United States Patent [19]

**Tangri**

[11] **4,085,709**  
[45] **Apr. 25, 1978**

[54] **HYDROGEN FUEL SYSTEM FOR A VEHICLE**

[76] Inventor: **Kuldip Chand Tangri**, 5126 W. Concord, Chicago, Ill. 60639

[21] Appl. No.: **637,736**

[22] Filed: **Dec. 4, 1975**

[51] Int. Cl.<sup>2</sup> ..... **F02B 43/10**

[52] U.S. Cl. .... **123/1 A; 123/DIG. 12; 123/3; 123/119 E**

[58] Field of Search ..... **123/DIG. 12, 3, 1 R, 123/1 A, 119 E; 180/65 B, 65 A**

[56] **References Cited**

**U.S. PATENT DOCUMENTS**

1,876,879	9/1932	Drabold .....	123/DIG. 12
2,365,330	12/1944	Carmichael .....	123/DIG. 12
3,459,953	8/1969	Hughes et al. ....	123/DIG. 12
3,608,660	9/1971	Smith et al. ....	123/DIG. 12
3,648,668	3/1972	Pacheco .....	123/DIG. 12
3,672,341	6/1972	Smith et al. ....	123/DIG. 12

3,696,795 10/1972 Smith et al. .... 123/DIG. 12  
3,939,806 2/1976 Bradley ..... 123/3

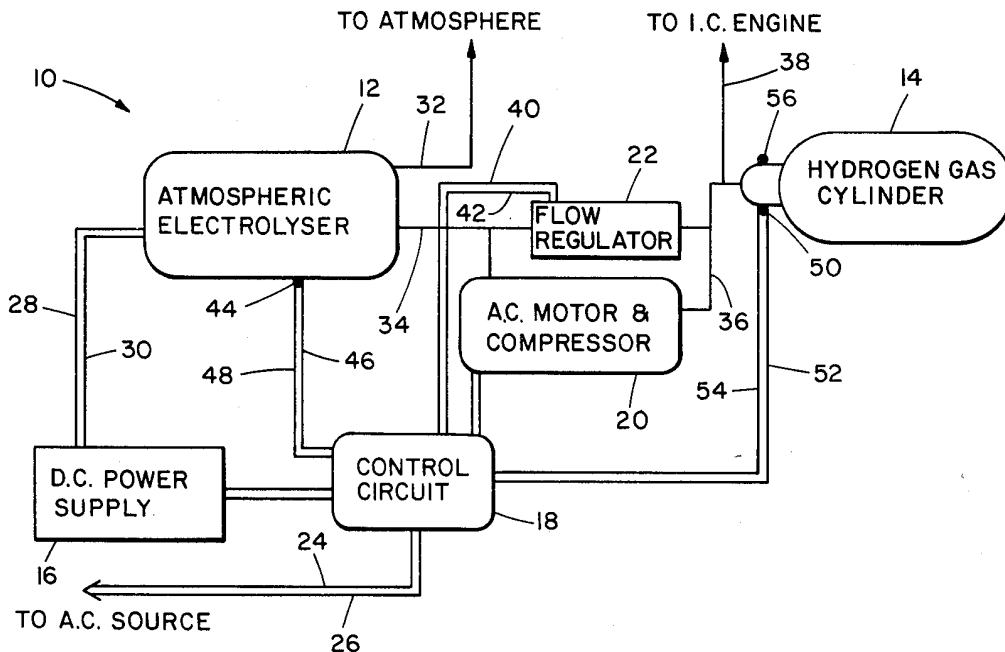
*Primary Examiner*—Charles J. Myhre

*Assistant Examiner*—Ira S. Lazarus

[57] **ABSTRACT**

The system is used with an internal combustion engine, is mounted on a vehicle and is operable primarily when the vehicle is at rest for generating and storing hydrogen gas on the vehicle. The system includes a gas cylinder, an electrolyzer connected to the gas cylinder, a D.C. power supply connected to the electrolyzer and including electrical apparatus for converting A.C. current to D.C. current and a control circuit connected to the D.C. power supply, to the electrolyzer, and to the gas cylinder, all of which are mounted within the vehicle. The control circuit for controlling generation and storage of hydrogen gas is operable from and connectible to a conventional A.C. source.

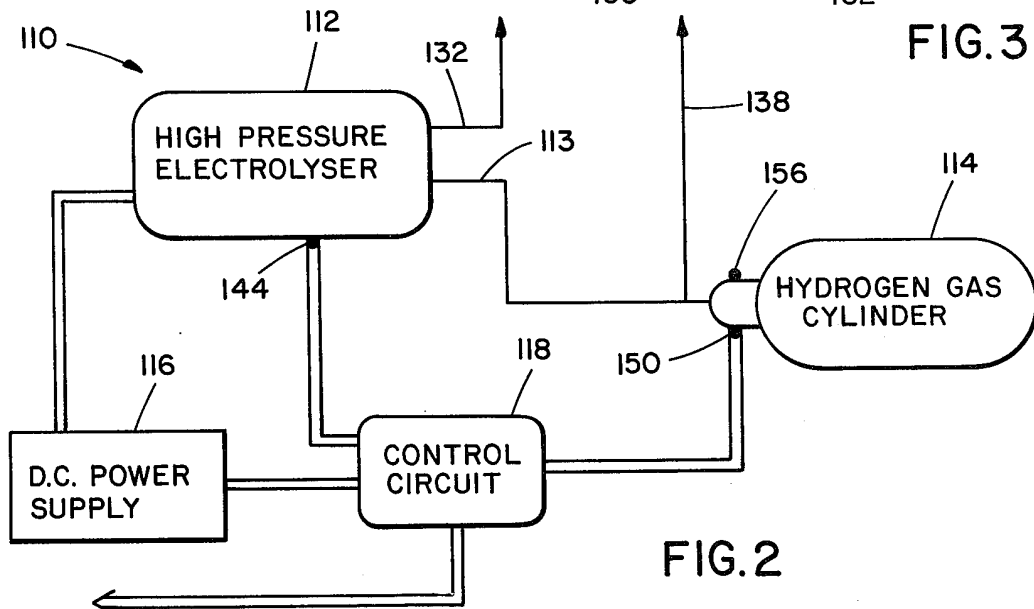
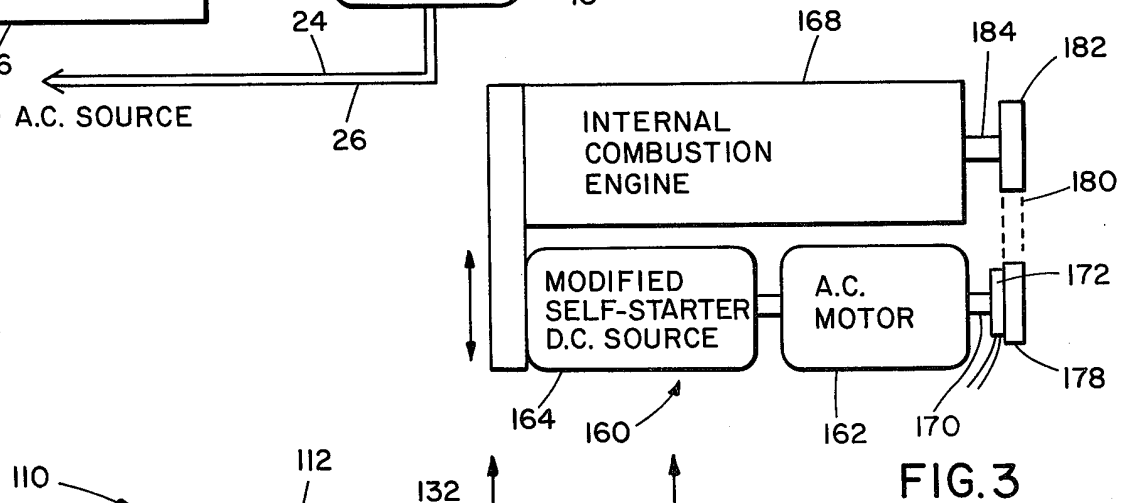
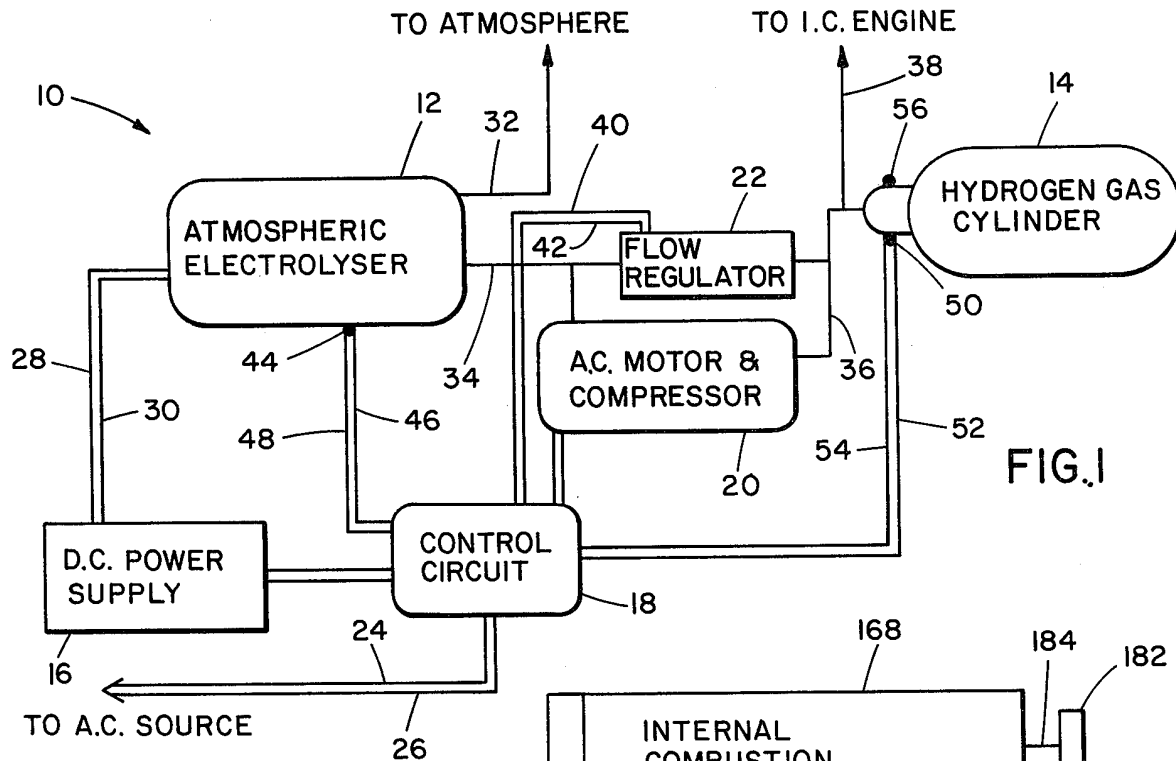
**12 Claims, 3 Drawing Figures**



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# HYDROGEN FUEL SYSTEM FOR A VEHICLE

## BACKGROUND OF THE INVENTION

### 1. The Field of the Invention

The field of the invention is a hydrogen fuel system for a vehicle powered by an internal combustion engine. Many systems of this type are presently classified in Class 123, subclass 1.

### 2. Description of the Prior Art

Heretofore, various proposals have been made for utilizing hydrogen gas as a fuel for internal combustion engines. Recently there has been greater interest in the use of hydrogen as a fuel for internal combustion engines, particularly for automobile engines in place of gasoline, in view of (1) the problem of air pollution and (2) the depletion of the world's oil supply from which gasoline is derived. Also, hydrogen is becoming more attractive as a fuel since: (1) more energy is derived from the combustion of a given amount of hydrogen than is obtained from an equivalent amount, by weight, of gasoline; (2) hydrogen is easily obtained from the electrolysis of water which is in great abundance; and (3) the main product of combustion of hydrogen is water which does not contaminate the environment. The recent interest in hydrogen as a fuel for internal combustion engines is exemplified by the experimental hydrogen fueled automobile described in a pamphlet entitled, "UCLA HYDROGEN CAR" published as Paper No. 730,507 by the Society of Automotive Engineers in May, 1973.

Hydrogen gas is very explosive and therefore requires special handling. In view of the special problems that arise in handling hydrogen gas, various proposals have been made relative to the generation, storage and use of hydrogen gas in a vehicle. In this respect, reference may be had to the various hydrogen systems disclosed in the following patents: U.S. Pat. Nos.: 3,572,297, 3,608,529, 3,648,668, 3,672,341.

In U.S. Pat. No. 3,608,529 it is proposed to locate an electrolyzer at a service station. Hydrogen and oxygen storage tanks are also situated at the service station for collecting hydrogen and oxygen from the electrolyzer. The service station also will have suitable outlets for connecting the storage tanks to conduits in a vehicle leading to respective hydrogen and oxygen storage tanks mounted on the vehicle. This arrangement requires valves in the outlets from the service station storage tanks and valves in the conduits leading to the vehicle storage tanks.

In U.S. Pat. No. 3,648,668, it is proposed to mount a hydrogen gas generator on the vehicle along with a pump and reserve tank. Also, to increase the output of hydrogen gas from the hydrogen gas generator, this patent proposes the use of a magnesium electrode which will decompose and need frequent replacement.

As will be described in detail hereinafter, the hydrogen fuel system of the present invention provides a relatively self-contained system for fueling an internal combustion engine on a vehicle with hydrogen gas, which system is mounted on the vehicle and does not require frequent replacement of electrodes or frequent connection and disconnection to hydrogen gas storage tanks.

## SUMMARY OF THE INVENTION

According to the invention, there is provided a hydrogen fuel system for a vehicle powered by an internal

combustion engine, said system being mounted on the vehicle and comprising gas storage means for storing hydrogen gas, said storage means being connected to a fuel input for the internal combustion engine, an electrolyzer for generating hydrogen gas which is stored in said gas storage means, a D.C. power supply having an output connected to said electrolyzer and including means for converting A.C. current to D.C. current, and control circuit means connected to said D.C. power supply, to said electrolyzer and to said gas storage means for controlling the generation and storage of hydrogen gas, said control circuit means being operable from and connectible to a conventional A.C. source.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic, block diagram of one embodiment of the hydrogen fuel system of the present invention;

FIG. 2 is a schematic, block diagram of another embodiment of the hydrogen fuel system of the present invention; and

FIG. 3 is a schematic, block diagram showing the use of an A.C. motor-D.C. generator set for the D.C. power supply of the hydrogen fuel system.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawing in greater detail, one embodiment of the hydrogen fuel system of the present invention is schematically illustrated in FIG. 1 and generally identified by reference numeral 10. The system 10 is mounted on a vehicle (not shown) and includes an internal combustion (I.C.) engine (not shown in FIG. 1), an electrolyzer 12, a hydrogen gas storage cylinder 14, a D.C. power supply 16, a control circuit 18, an A.C. motor-compressor unit 20, and a flow regulator 22.

The control circuit 18 is adapted to be connected via input lines 24 and 26 to a conventional A.C. source and is operable to supply A.C. current to the D.C. power supply 16 which converts the A.C. current to regulated D.C. current which is supplied via conductors 28 and 30 to the electrolyzer 12.

The electrolyzer 12 operates under atmospheric conditions and for that reason is identified as an atmospheric electrolyzer. An oxygen output 32 from the electrolyzer 12 is vented to atmosphere and a hydrogen gas output 34 is connected to the input of a motor-compressor unit 20. An output 36 of the unit 20 is connected to an input to the hydrogen gas cylinder 14 and to a fuel line 38 leading to the I.C. engine. The flow regulator 22 is connected between the input-output of the motor-compressor unit 20 and is connected via conductors 40 and 42 to the control circuit 18.

The electrolyzer 12 is provided with a sensing or monitoring device generally identified by reference numeral 44 which is connected via conductors 46 and 48 to the control circuit 18. The hydrogen gas cylinder 14 is also provided with a sensor or monitoring device generally identified by reference numeral 50, which is connected via conductors 52 and 54 to the control circuit 18. Additionally, the hydrogen gas cylinder 14 has a venting valve 56 for relieving the pressure of hydrogen gas in the cylinder 14.

The D.C. power supply 16 includes a regulator of known type (not shown) for regulating the D.C. voltage and/or current supplied to the electrolyzer 12 and apparatus for converting the A.C. current to D.C. current,

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such as rectifiers or a motor-generator set as will be explained in more detail in connection with the description of FIG. 3.

The system 10 is operable primarily when the vehicle is at rest, in other words, when the vehicle is parked in the owners garage. At that time the lines 24 and 26 are connected to a suitable A.C. source via a male-female plug arrangement. The control circuit 18 will then energize the D.C. power supply 16 which provides regulated D.C. current to the electrolyzer 12 which in turn begins generating oxygen and hydrogen. The control circuit 18 also causes operation of the motor-compressor unit 20 so that hydrogen gas at the outlet 34 of the electrolyzer 12 is compressed and then supplied to the cylinder 14.

It is to be understood that the electrolyzer 12 is of known type and the hydrogen outlet 34 has a one way valve (not shown) which permits hydrogen gas to escape from the electrolyzer 12 but which will stop hydrogen gas from flowing back into the electrolyzer 12. Also it is to be understood that the fuel line 38 has a valve therein (not shown) which prevents gas from flowing to the I.C. engine when the engine is not running. In this way, the cylinder 14 is filled with the hydrogen gas produced by electrolyzer 12 and compressed by the motor-compressor unit 20.

When a sufficient amount of hydrogen gas has been generated and stored in the cylinder 14, the sensor 50 will cause the control circuit 18 to de-energize the power supply 16 and the motor-compressor unit 20. Also, if an abnormality in the operation of the electrolyzer 12 is sensed by the sensor 44, the control circuit 18 will de-energize the D.C. power supply 16 and the motor-compressor unit 20.

If for some reason the electrolyzer 12 does not produce sufficient hydrogen gas such that the motor-compressor unit 20 creates a vacuum at the hydrogen gas outlet 34, the flow regulator 22 will operate to cause hydrogen gas to be circulated through the motor-compressor unit 20. If the amount of recirculation is excessive, the flow regulator 22 will send a signal via the conductors 40 and 42 to the control circuit 18 to cause the control circuit 18 to de-energize the power supply 16 and the motor-compressor unit 20.

In FIG. 2 there is illustrated a modified hydrogen fuel system 110 constructed in accordance with the teachings of the present invention. In the system 110, the flow regulator 22 and the motor-compressor unit 20 are eliminated. Instead, the system 110 utilizes a high pressure electrolyzer 112 of known type having a hydrogen gas outlet 113 which is connected directly to, and which supplies pressurized hydrogen gas directly to, a hydrogen gas cylinder 114. In other respects, the system 110 is identical to the system 10 and includes a D.C. power supply 116, a control circuit 118, an oxygen vent 132 from the electrolyzer 112 and a fuel line 138 leading from the input-output to the gas cylinder 114. Additionally a monitoring device or sensor 144 is associated with the electrolyzer 112 and connected to the control circuit 118. Likewise the hydrogen gas cylinder 114 has a monitor or sensing device 150 connected to the control circuit 118 and has a venting valve 156. The hydrogen fuel system 110 functions in essentially the same manner as the hydrogen fuel system 10.

As stated above, the D.C. power supply 16 or 116 may include static, solid-state rectifiers of known type or a dynamic, motor-generator unit for converting A.C. current to D.C. current. In FIG. 3 there is illustrated an

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A.C. motor-D.C. generator unit 160 comprising an A.C. motor 162 and a D.C. generator 164. The D.C. generator 164 is actually a modified D.C. starter motor utilized in starting an internal combustion engine generally identified by the reference numeral 168. The modified starter motor 164 for the I.C. engine 168 is modified by having a compound wound stator which, through suitable connections and switches, is connected as a D.C. motor when it is utilized for starting the I.C. engine 168. However, it is connected as a D.C. shunt generator when it is driven by the A.C. motor 162. It will be understood that when the motor-generator 164 is used as a starter motor, it is moved into engagement with the fly wheel for the internal combustion engine 168. However, when the engine 168 is running or is at rest, the D.C. motor-generator 164 will be disengaged from the fly wheel.

When the engine 168 is at rest and the control circuit 18 is actuated, the A.C. motor 162 is energized and drives the D.C. motor-generator 164 as a generator. The regulated output current and voltage from the generator 164 is then supplied to the electrolyzer 12 or 112.

It has been found that the fuel value of hydrogen generated by electrolysis is 120% of the heating value of the electrical energy supplied to generate the hydrogen at 25° C. Thus, under ideal conditions a water electrolyzer could have a theoretical "thermal" efficiency of up to 120%. This characteristic of hydrogen is more fully described in a book entitled "Hydrogen as a Fuel", distributed by the National Technical Information Service of the U.S. Department of Commerce under catalog no. AD-787 484, published Aug. 31, 1974. Since theoretically a net gain in energy can be obtained through the electrolysis-combustion of hydrogen and since there are many operating conditions of a vehicle where the I.C. engine is operating at idle, it may be economical to operate the electrolyzer 12 or 112 during operation of the engine 168. For this purpose, a shaft 170 of the A.C. motor 162 is connected via an electric clutch 172 to a pulley 178 coupled by a belt 180 to a pulley 182 mounted on an output shaft 184 of the I.C. engine 168. Suitable electrical circuitry is provided in the control circuit 18 or 118 to cause actuation of the clutch 172 when the engine 168 is running. Also, if desired such circuitry can be actuated only when the vehicle is not moving.

Also, to ensure adequate generation of hydrogen within a relatively constant operating temperature range, the electrolyzer 12 or 112 can be equipped with a suitable heating or cooling apparatus.

Although conventional hydrogen gas cylinders 14 or 114 can be provided for storing the hydrogen gas, the system 10 or 110 can also utilize compartments in the chassis or frame of the vehicle. In this respect portions of the frame can be made of heavy duty metal tubes providing hollow compartments therein which can serve as storage space for hydrogen gas generated by the electrolyzer 12 or 112. Since hydrogen has a small molecule, hydrogen gas cylinders are normally thick and rather heavy. Thus, by utilizing thick metal tubes not only for segments of the vehicle frame but also as storage space for the hydrogen gas, a space and weight savings can be obtained. In other words, since hollow compartments within portions of the frame are being utilized for storing the hydrogen gas, the need for separate gas cylinders is eliminated.

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From the foregoing description it will be apparent that the hydrogen fuel system 10 or 110 of the present invention has a number of advantages some of which have been described above and others of which are inherent in the invention. Of course, the principal advantage of the system 10 or 110 is that it is a substantially self-contained unit which does not require handling of the hydrogen gas. In this respect the only regular maintenance required for the system 10 or 110 is the refilling of the electrolyzer with water. Also the system 10 or 110 does not require the need for special electrodes or the need for periodically recharging the gas cylinders with hydrogen gas. Instead, an operator can utilize electrical energy supplied from the local electric utility for generating hydrogen gas.

Also, it will be apparent from the foregoing description that various modifications and variations can be made to the hydrogen fuel system of the present invention, some of which modifications and variations have been described above, without departing from the spirit or scope of the invention. Accordingly, the scope of the invention is only to be limited as necessitated by the accompanying claims.

I claim:

1. A hydrogen fuel system for a vehicle powered by an internal combustion engine, said system being mounted on the vehicle and comprising gas storage means for storing hydrogen gas, said storage means being connected to a fuel input for the internal combustion engine, an electrolyzer for generating hydrogen gas which is stored in said gas storage means, a D.C. power supply having an output connected to said electrolyzer and including means for converting A.C. current to D.C. current, and control circuit means connected to said D.C. power supply to said electrolyzer and to said gas storage means for controlling the generation and storage of hydrogen gas, said control circuit means being operable from and connectible to a conventional A.C. source.

2. The system according to claim 1 wherein said D.C. power supply includes rectifying circuit means for rectifying A.C. current to D.C. current.

3. The system according to claim 1 wherein said electrolyzer operates at atmospheric pressure and said system further includes a gas compressor connected between the output of said electrolyzer and said gas storage means and driven by an A.C. motor connected to said control circuit means.

4. The system according to claim 3 including a flow regulator connected between the input and output of

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said compressor and wherein said control circuit means is connected to said flow regulator and is operative when said flow regulator bypasses an excessive amount of hydrogen gas from the output to the input of said compressor to stop operation of said electrolyzer and said A.C. motor driving said compressor.

5. The system according to claim 1 wherein said electrolyzer is a high pressure electrolyzer and the hydrogen gas output from said electrolyzer is connected directly to said gas storage means.

6. The system according to claim 1 wherein said means for converting A.C. current to D.C. current includes a motor-generator set comprising an A.C. motor electrically connected to said control circuit means and a D.C. generator mechanically coupled to said A.C. motor.

7. The system according to claim 6 wherein said D.C. generator is a modified D.C. starter motor which is utilized for starting the internal combustion engine and which is modified so that when driven by said A.C. motor it produces D.C. current and wherein said D.C. power supply regulates the D.C. current supplied by said D.C. generator to said electrolyzer.

8. The system according to claim 7 wherein said A.C. motor is coupled through an electric clutch mechanism to an output shaft of the internal combustion engine and wherein said control circuit means are operable to energize said electric clutch mechanism whereby said A.C. motor can be mechanically driven by the internal combustion engine.

9. The system according to claim 1 wherein said control circuit means includes means for monitoring the operation of said electrolyzer and are operative to stop operation of said electrolyzer when said monitoring means senses an abnormality in the operation thereof.

10. The system according to claim 1 wherein said gas storage means has a venting valve and said control circuit means includes monitoring means which are connected to said gas storage means and are operative to stop operation of said electrolyzer and, if necessary, to open said venting valve when said monitoring means senses a predetermined maximum pressure.

11. The system according to claim 1 wherein said gas storage means is a gas cylinder.

12. The system according to claim 1 wherein said gas storage means includes compartments provided in a supporting framework for the vehicle mounting said system.

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**United States Patent** [19]

Laumann et al.

[11] **4,112,875**[45] **Sep. 12, 1978****[54] HYDROGEN-FUELED ENGINE**

[76] Inventors: **James C. Fletcher**, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Eugene A. Lauman, Pasadena; **Rollin K. Reynolds**, Tujunga, both of Calif.

[21] Appl. No.: **718,268**[22] Filed: **Aug. 27, 1976**[51] Int. Cl.<sup>2</sup> ..... **F02B 75/12; F02B 43/08**[52] U.S. Cl. .... **123/1 A; 123/3; 123/DIG. 12**[58] Field of Search ..... **123/1 A, 3, 119 A, 119 E, 123/DIG. 12; 204/129; 431/2, 4****[56] References Cited****U.S. PATENT DOCUMENTS**

1,905,627	4/1933	Holland	123/119 E
2,169,844	8/1939	Marshall	123/119 E
2,183,674	12/1939	Erren	123/DIG. 12
2,742,885	4/1956	Thwaites	123/119 A
2,937,634	5/1960	Kelseaux	123/DIG. 12
3,459,953	8/1969	Hughes	123/119 E
3,572,297	3/1971	Murray	123/119 E
3,672,341	6/1972	Smith	123/119 E
3,970,054	7/1976	Henault	123/DIG. 12

3,982,878	9/1976	Yamane	431/4
4,003,345	1/1977	Bradley	123/DIG. 12

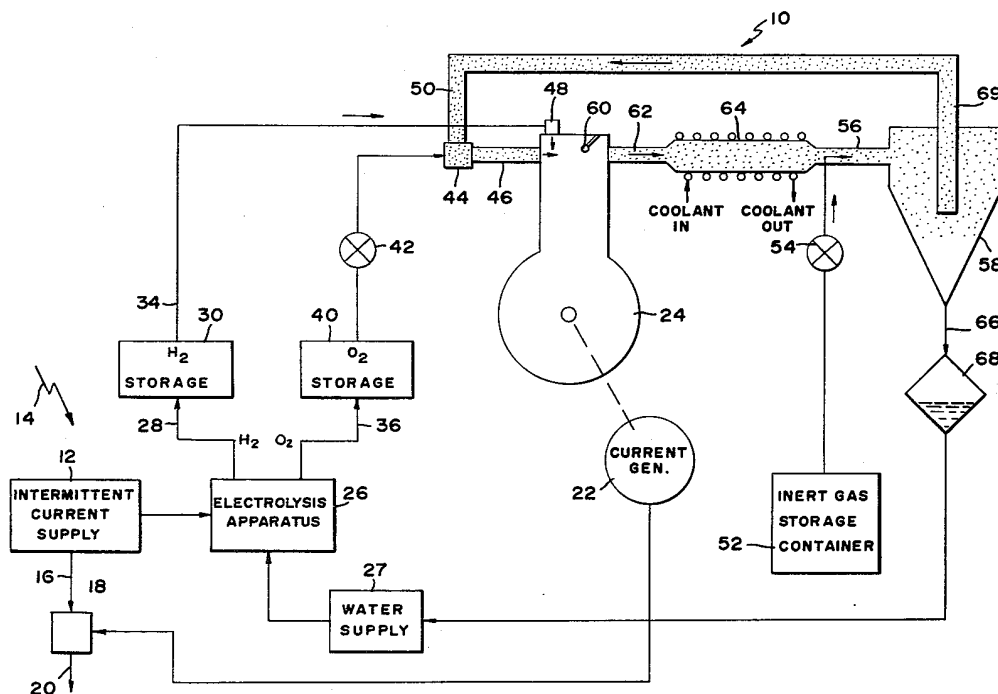
**FOREIGN PATENT DOCUMENTS**

831,429 12/1937 France ..... 123/DIG. 12

*Primary Examiner*—Charles J. Myhre  
*Assistant Examiner*—Craig R. Feinberg  
*Attorney, Agent, or Firm*—Wilfred Grifka; John R. Manning; Monte F. Mott

**[57] ABSTRACT**

A hydrogen-oxygen fueled internal combustion engine is described herein, which utilizes an inert gas, such as argon, as a working fluid to increase the efficiency of the engine, eliminate pollution, and facilitate operation of a closed cycle energy system. In a system where sunlight or other intermittent energy source is available to separate hydrogen and oxygen from water, the oxygen and inert gas are taken into a diesel engine into which hydrogen is injected and ignited. The exhaust is cooled so that it contains only water and the inert gas. The inert gas in the exhaust is returned to the engine for use with fresh oxygen, while the water in the exhaust is returned to the intermittent energy source for reconversion to hydrogen and oxygen.

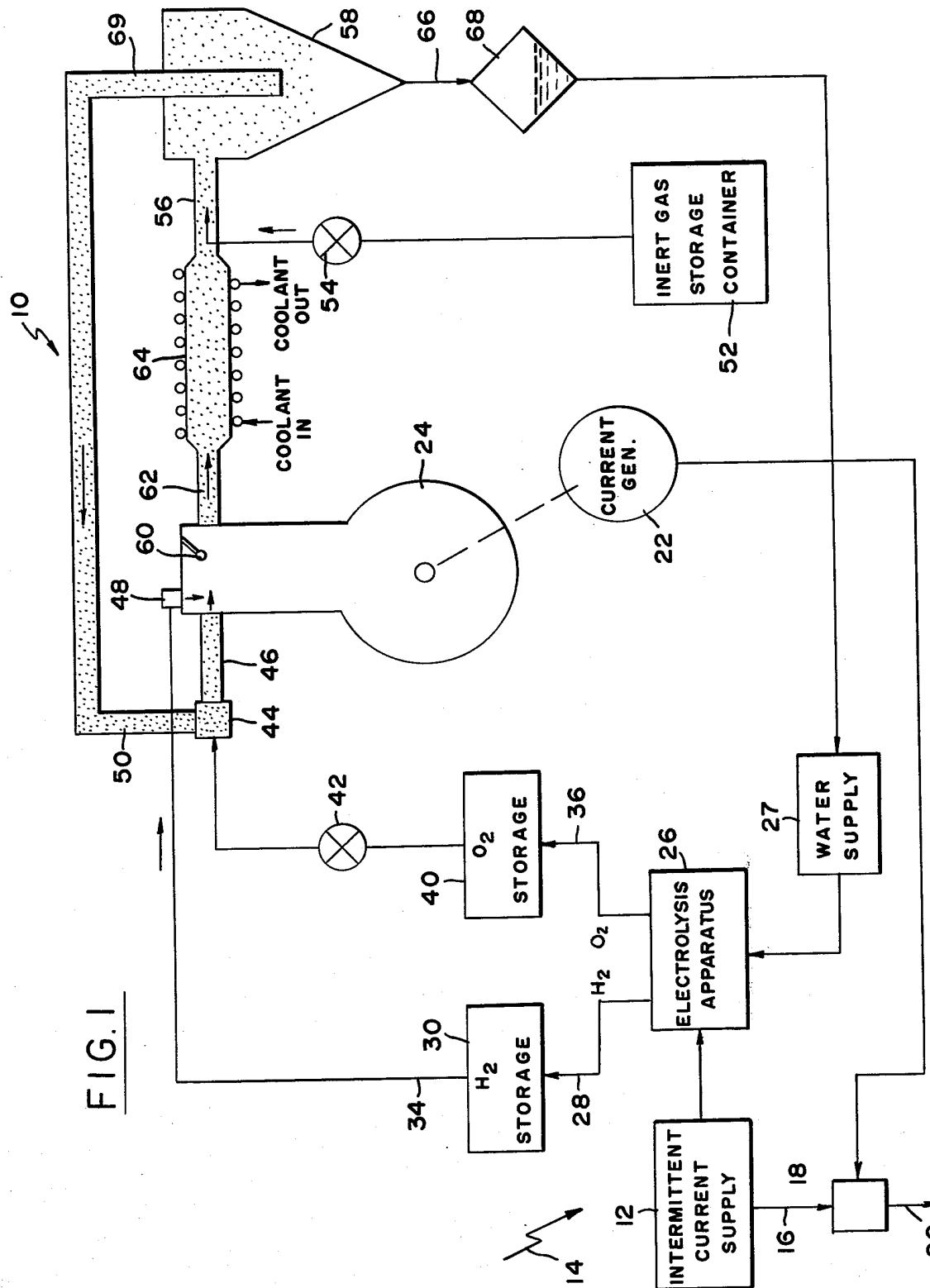
**6 Claims, 2 Drawing Figures**

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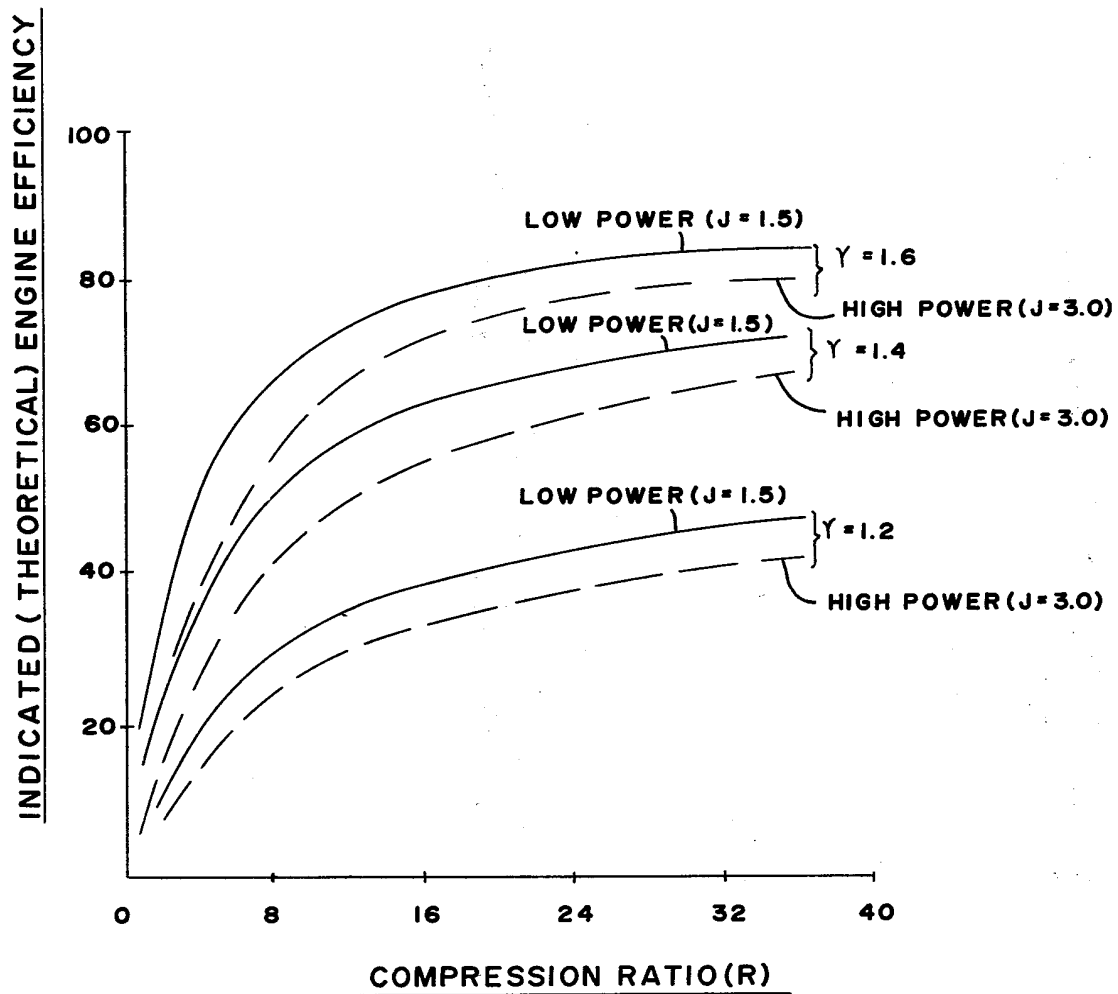
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FIG. 2



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## HYDROGEN-FUELED ENGINE

### ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

### BACKGROUND OF THE INVENTION

This invention relates to hydrogen fueled engines.

Considerable efforts have recently been directed towards utilizing intermittent natural power sources, such as sunlight, to generate hydrogen for use when power is not available from the natural source. Hydrogen can be utilized as the fuel in a diesel engine, in combination with air. However, if an engine with a high compression ratio is utilized to increase the efficiency of operation, then nitrous oxide pollution is generated. A system which substantially eliminated such pollution, while also providing greater efficiency in engine operation, would enable the production of mechanical or electrical energy at lower cost.

### SUMMARY OF THE INVENTION

In accordance with the present invention, a hydrogen-fueled energy system is provided which is of high efficiency and which produces substantially no pollution. The system includes an engine powered by hydrogen and oxygen, with an inert gas as a working fluid. The inert gas permits operation at very high thermal efficiencies for any given volumetric compression ratios. The exhaust of the engine contains substantially no pollutants, and can be cooled to separate liquid water from the working fluid. The working fluid can be returned to the engine, while the water can be utilized in the production of hydrogen and oxygen.

The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a simplified diagram of a closed cycle, hydrogen-fueled energy system, constructed in accordance with the present invention; and

FIG. 2 is a graph showing the theoretical efficiency of hydrogen-fueled engines.

### DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 illustrates a closed cycle energy system 10, which is based on the use of hydrogen as a fuel. The system includes an intermittent current supply 12 in the form of a bank of solar cells which receives sunlight 14 and converts it to current. During sunny days, the supply provides current over line 16 which flows through a switch 18 to an output line 20 for transmission to electricity users. On very cloudy days and at night, current is supplied through the switch 18 to the output line 20, by a current generator 22 which is driven by a diesel engine 24. During sunny days, the intermittent supply 12 also supplies current to an electrolysis apparatus 26 which receives water from a water supply 27 and separates the water into hydrogen and oxygen. The hydrogen is delivered over line 28 to a hydrogen storage device 30 which can supply pressured hydrogen on

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its output line 34. An oxygen outlet 36 of the electrolysis apparatus delivers oxygen to an oxygen storage device 40 which supplies pressured oxygen. The oxygen supply 40 delivers the oxygen through a control valve 42 to a carburetor 44, and the outlet 46 of the carburetor is connected to the engine 24 to supply oxygen thereto. At the same time, hydrogen from the hydrogen supply outlet 34 is delivered to an injection valve 48 which injects the hydrogen into the engine 24.

In accordance with the present invention, the working fluid, an inert gas, is supplied through a pipe 50 to the carburetor 44 to mix with the oxygen therein, so that a mixture of oxygen and the inert gas is supplied from the carburetor outlet 46 to the engine. The inert gas is initially supplied from an inert gas storage container 52 through a control valve 54 to a pipe 56 which leads to a separator 58, the inert gas in the separator 58 flowing through the pipe 50 to the carburetor 44. The proportion of inert gas, of the oxygen-inert gas mixture, is preferably great enough to constitute a majority of the mass of the mixture, and in any case should constitute more than 10%, by weight, of the oxygen-inert gas mixture.

The invention can better be understood by following the complete cycle of operation as illustrated in FIG. 1. The diesel engine 24 receives a mixture of oxygen and inert gas from the carburetor 44, and receives injected hydrogen from the injector valve 48. A glow plug 60 assures combustion of the hydrogen and oxygen to produce high pressures that move the pistons of the diesel engine. An exhaust 62 of the engine carries away the products of combustion, which includes the combined hydrogen and oxygen, in the form of steam, some residual oxygen, and the inert gas. The exhaust moves through a cooler 64 which cools the exhaust so that the steam condenses to liquid water. The exhaust passes through the pipe 56 to the separator 58, where the water falls through an outlet 66 into a gathering tank 68 which leads back to the water supply 27. The inert gas 69 in the separator 58 remains gaseous, and passes through the pipe 50 to the carburetor 44 for reuse. The inert gas storage container 52 makes up for losses of the inert gas by supplying small quantities to the system. The water in the water supply 27 is supplied to the electrolysis apparatus 26 so that it can be separated into hydrogen and oxygen for reuse in the engine. Any uncombusted oxygen and/or hydrogen is returned with the argon, through the pipe 50 for reuse. If significant amounts of carbonates or unreacted hydrocarbons are present in the exhaust (due to lubricating oil in the engine) then the carbonates and light hydrocarbons can be removed with an absorption filter and the heavy hydrocarbons can be filtered out of the water. Excessive hydrogen can be removed with a catalyst, or less hydrogen can be injected into the engine to account for hydrogen in the exhaust. Normally, a substantially stoichiometric ratio of hydrogen to oxygen is passed into the engine, although some excess oxygen can be admitted to help achieve complete combustion, the excess oxygen not being wasted since it is recycled.

The usefulness of the inert gas arises from the fact that the proper selection of the inert gas permits operation of the engine at higher thermal efficiencies than otherwise possible, and with no pollution of the atmosphere.

If it were possible to operate a diesel engine at conventional compression ratios, utilizing only oxygen and hydrogen at complete combustion, then excessive tem-

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peratures would be created that could harm the engine, when the engine were operated at close to its maximum power output: Actually, complete combustion of hydrogen and oxygen in a stoichiometric ratio (the ratio which permits complete combination) does not occur because of the quenching effect of the steam created by some of the combustion gases. When air, which contains nitrogen and oxygen, is utilized instead of pure oxygen, a lower power output is produced and the properties of nitrogen result in the production of nitrogen oxides which pollute the atmosphere.

There are several thermodynamic properties of gases that affect the efficiency of a reciprocating, internal combustion engine. Three of these properties are the specific heat of the gas at constant pressure ( $C_p$ ), the specific heat ratio  $\gamma$  of the gas which equals the specific heat at constant pressure ( $C_p$ ) divided by the specific heat at constant volume ( $C_v$ ), and the thermal conductivity of the gas. An ideal diluent gas has a low specific heat at constant pressure ( $C_p$ ), a high ratio of specific heats ( $\gamma$ ), and a low thermal conductivity.

The desirability of having low thermal conductivity arises from the fact that this will cause minimal heat loss to the walls of the cylinder in which the combusted gases lie. Low thermal conductivity also minimizes the amount of engine cooling that is required.

The desirability of employing a working fluid of low specific heat arises from the fact that such a gas will achieve a higher pressure when heated, as by the combustion of hydrogen and oxygen. Thus, for a given amount of heat resulting from combustion, the gas will rise to a higher pressure than a gas with a high specific heat. This raises the specific output of a given size engine, and as losses are mostly a function of engine size and configuration, the ratio of power output to power loss increases.

The desirability of utilizing a working fluid of large specific heat ratio  $\gamma$ , arises from its ability to produce high peak cylinder pressures under adiabatic compression, and maximum energy extraction during the expansion phase of the engine cycle. The theoretical efficiency of an engine operating at various compression ratios  $R$ , combustion intervals  $J$ , and specific heat ratios  $\gamma$  are shown in the graph of FIG. 2. The combustion interval  $J$ , with gaseous nitrogen as a fuel, is essentially the interval during which hydrogen is injected and combusted. Specifically,  $J$  equals the cylinder volume at the end of combustion (which normally occurs a short time after injection of fuel ceases), divided by the minimum cylinder volume (when the piston is at top dead center). The injection of gaseous hydrogen normally occurs between the time a piston reaches top dead center and the time it reaches a point less than 30° past top dead center. A long injection schedule sustains the pressure to increase the power output of the engine, but reduces the theoretical efficiency of the engine since much of the pressure is lost at the end of the piston stroke. The compression ratio  $R$  is the ratio between the volume within the cylinder at the beginning of compression by the piston, to the volume at top dead center when the volume within the cylinder is a minimum. Although the theoretical efficiency can be maximized by using a large compression ratio, physical limitations exist and increased mechanical losses are produced at higher compression ratios. Thus, a major factor which is available to increase efficiency is the specific heat ratio  $\gamma$ .

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A formula for indicated (theoretical) engine efficiency  $N$ , as a function of the compression ratio  $R$ , the combustion duration interval  $J$ , and the ratio of specific heats  $\gamma$  is given below:

$$N = 1 - \frac{1}{R^{(\gamma-1)}} \left| \frac{J^{\gamma-1}}{\gamma^{(J-1)}} \right| \quad \text{Equation 1}$$

FIG. 2 provides graphs of the theoretical efficiencies at different compression ratios  $R$ , combustion intervals  $J$ , and specific heat ratios  $\gamma$ . It can be seen that the use of a gas of high specific heat ratio  $\gamma$ , such as 1.6, can produce a considerably higher efficiency than can be produced with gases of lower specific heat ratio. For example, at a combustion interval of 1.5 and a compression ratio of 16, a gas of a specific heat ratio  $\gamma$  of 1.6 provides a theoretical efficiency of approximately 78%, while a gas with a specific heat ratio  $\gamma$  of 1.4 (equal to that of air) provides a theoretical efficiency of about 63%, or in other words about 19% less.

The following table provides a comparison of the above-described properties of different gases which can be utilized in an engine:

Sub- stance	$C_p$ (Constant) Pressue	Specific Heat $\text{Cal—gm}^{-1}—^{\circ}\text{K}^{-1}$		Thermal Conductivity $\text{cal—cm}^{-1}—\text{sec}^{-1}—\text{K}^{-1}$
		$C_v$ (Constant) Volume	$\gamma$ ( $C_p/C_v$ )	
Air	.2404	.1715	1.401	$7.197 \times 10^{-5}$
H <sub>2</sub>	3.428	2.442	1.404	$49.94 \times 10^{-5}$
O <sub>2</sub>	.2187	.1563	1.399	$7.427 \times 10^{-5}$
CO <sub>2</sub>	.2064	.1626	1.281	$5.06 \times 10^{-5}$
NO <sub>2</sub>	—	—	—	$8.88 \times 10^{-5}$
He	1.248	.752	1.660	$39.85 \times 10^{-5}$
Ar	.1252	.07531	1.668	$4.238 \times 10^{-5}$
Kr	.04	.0238	1.68	$2.26 \times 10^{-5}$
Ne	.25	.152	1.64	$11.75 \times 10^{-5}$
Xe	.04	.024	1.66	—
N <sub>2</sub>	.248	.177	1.40	$7.18 \times 10^{-5}$
Steam	.4801	.3657	1.310	$5.510 \times 10^{-5}$

It can be seen that the noble gases (He, Ar, Kr, Ne, and Xe), which are monatomic, all have a high specific heat ratio  $\gamma$  of more than 1.6, which is considerably more than the specific heat ratio of 1.4 for air which is composed primarily of diatomic gases. As described above, it is desirable to provide a gas of large  $\gamma$ , low  $C_p$  and low thermal conductivity. The optimal gas would be krypton, with argon being a close second choice. From a practical standpoint, argon is the best choice because of its availability, since argon constitutes approximately 1% of air while krypton constitutes only about one-ten thousandth of one percent of air. Argon can be obtained from air by liquifying the air.

A closed cycle energy system of the type illustrated in FIG. 1 can be used to produce energy in a variety of locations, such as in desert-like environments where large amounts of sunlight are available but water is not readily available. This is because substantially all of the water used to generate the fuel and oxidizer can be recovered, and the inert gas used as the working fluid can be easily separated from the rest of the exhaust and reused. Of course, inert gas can be effectively utilized in a hydrogen-powered engine for other applications, because of the higher efficiency of engine operation.

Thus, the invention provides a hydrogen-fueled engine of high efficiency and which produces substantially no pollution. This is accomplished by utilizing a mixture of oxygen and an inert gas, as the atmosphere

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within the engine in which the hydrogen is combusted. The inert gas is chosen so it has a large specific heat ratio of about 1.6 or more, and is inert in the presence of oxygen and hydrogen at a typical combustion temperature on the order of 3000° C to avoid the generation of pollutants. An especially appropriate inert gas is argon. This fueling arrangement enables the provision of a relatively simple closed cycle energy system, wherein the exhaust can be cooled to produce water and the inert gas, which are easily separated and which each can be recycled for reuse in the engine.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art and consequently it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. A method for operating a hydrogen-fueled internal combustion engine comprising:
  - introducing a mixture of oxygen and a working fluid into the cylinder of said engine;
  - compressing said mixture; and
  - injecting hydrogen into the cylinder, to combust the oxygen and hydrogen;
2. The method described in claim 1 including:
  - cooling the exhaust of said engine to convert the steam to water, and returning the gas in the cooled exhaust to the cylinder of said engine.
3. A method for operating a closed cycle energy system comprising:
  - separating hydrogen and oxygen out of water;

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delivering oxygen and a monatomic inert gas to the combustion chamber of an engine;  
compressing the oxygen and inert gas in said chamber;

injecting hydrogen into said chamber when the oxygen and inert gas therein are compressed, to raise the gas pressure, and then produce work while lowering the pressure;

cooling the exhaust gas from said engine to produce water and said inert gas, for reuse in engine operation.

4. A method for operating a hydrogen-fueled engine comprising:

introducing into a combustion chamber oxygen and an inert monatomic gas that is inert in the presence of oxygen and hydrogen at a temperature of 3000° C.;

compressing the oxygen and inert gas in said combustion chamber;

injecting hydrogen into said combustion chamber at a time when the oxygen and inert gas therein are compressed, and allowing said hydrogen to ignite; exhausting the gas in said combustion chamber; and extracting inert gas from the exhaust gas.

5. The method described in claim 4 wherein: said inert gas comprises primarily argon.

6. The method described in claim 4 wherein: said oxygen and hydrogen are introduced into said combustion chamber in a substantially stoichiometric ratio; so that the exhaust consists substantially of water and inert gas; and including

separating the water and inert gas in said exhaust and separating the water into oxygen and hydrogen.

\* \* \* \* \*

Dec. 19, 1939.

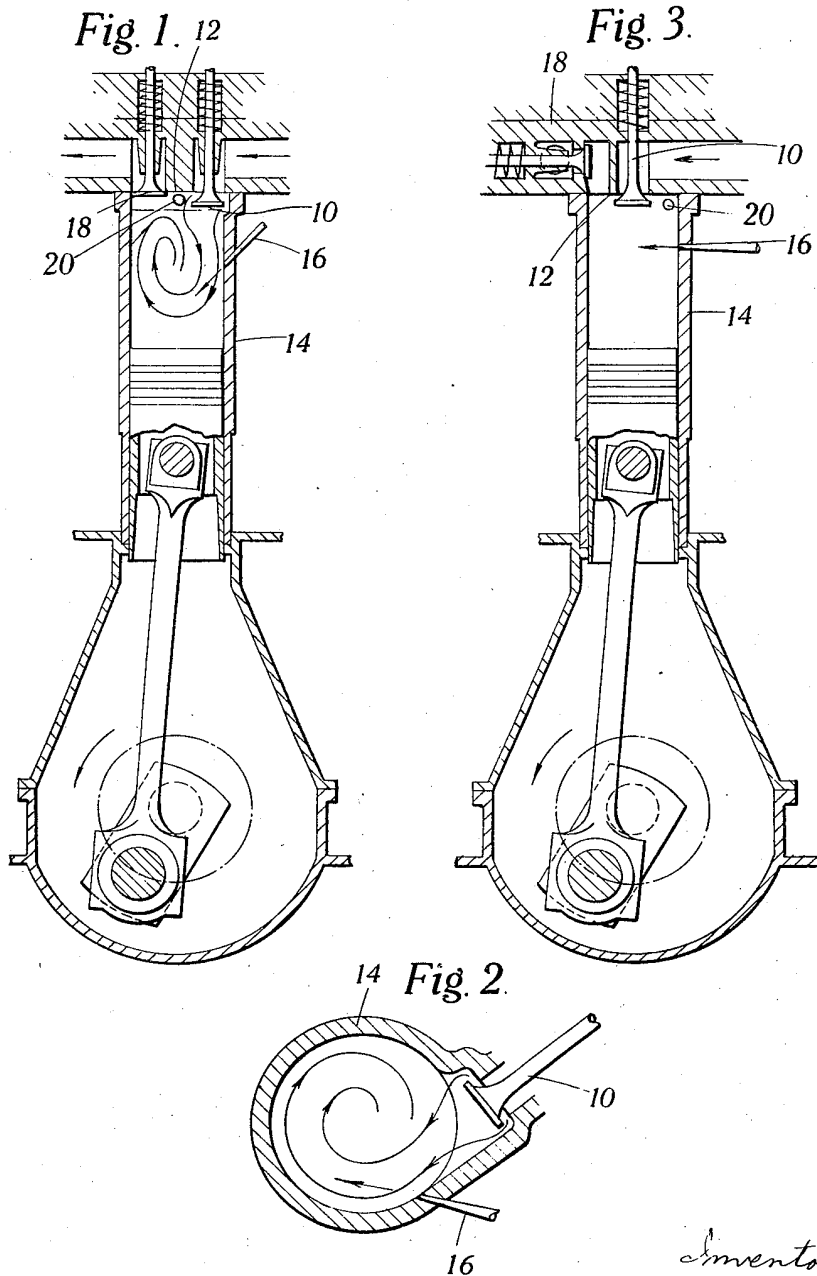
R. A. ERREN

2,183,674

INTERNAL COMBUSTION ENGINE USING HYDROGEN AS FUEL

Filed Sept. 10 1936

2 Sheets-Sheet 1



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Dec. 19, 1939.

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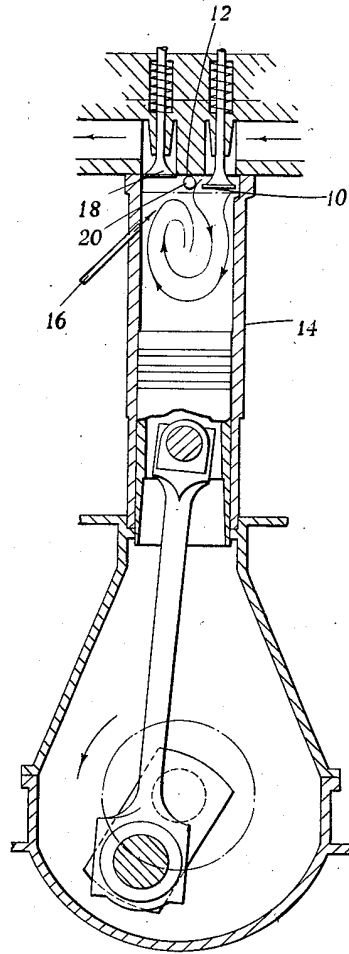
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INTERNAL COMBUSTION ENGINE USING HYDROGEN AS FUEL

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2 Sheets-Sheet 2

Fig. 4.



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2,183,674

## UNITED STATES PATENT OFFICE

2,183,674

INTERNAL COMBUSTION ENGINE USING  
HYDROGEN AS FUEL

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Application September 10, 1936, Serial No. 100,201  
In Great Britain September 12, 1935

## 1 Claim. (Cl. 123—27)

This invention relates to internal combustion engines in which hydrogen is injected into the cylinder under excess pressure after the oxygen (whether this is contained in air or is used in admixture with an expansion medium other than air, for example, steam) has been introduced into the cylinder.

It has been found in practice that inefficient working is sometimes obtained in such engines and experiments have shown that this inefficient working is due to insufficient mixing of the hydrogen and the other gases. In addition to inefficient working, in some conditions the engine may actually be destroyed by an explosion in the crankcase due to a cushion of unmixed hydrogen being formed immediately above the piston, this hydrogen escaping past the piston ring into the crankcase and being ignited by flames penetrating past the piston rings. In other cases back firing in the air intake pipe is caused by unmixed hydrogen escaping past the valve seating and being ignited in a similar manner.

It has been found that these disadvantages and dangers are avoided by the present invention according to which hydrogen is injected through a valve situated in the cylinder wall itself during the early part only of the compression stroke and preferably in a direction which makes an angle not greater than, and preferably less than, 90° to the direction in which the air or other gases are circulating in the cylinder in the region where the hydrogen is injected.

The injection of hydrogen begins preferably immediately the inlet valve has closed, that is, at latest at 220° of the cycle, and ends at latest at 280° of the cycle, the hydrogen injection pipe opening into the cylinder at that part of the cylinder wall traversed by the piston and above the lowest position of the piston.

Referring to the accompanying diagrammatic drawings,

Figure 1 represents a hydrogen internal combustion engine embodying the invention in one form, the view being a side elevation in cross-section,

Figure 2 represents a modified form of the invention, the view being a sectional plan of the engine cylinder,

Figure 3 is a view similar to Figure 1 illustrating a further modification, and

Figure 4 is a view similar to Figure 1 illustrating another modification.

The nature of the swirling motion within the cylinder varies according to the design of the cylinder head and of the inlet valve. In Figure

1 the air inlet valve 10 is shown mounted in the cylinder head 12 between the axis of the cylinder and the cylinder wall 14. The entering air will therefore swirl in a clockwise direction as shown by the arrows. According to the invention the hydrogen injection pipe 16 is placed either near the top of the cylinder wall 14 on the air inlet valve side of the cylinder and pointing obliquely downwards as shown in Figure 1, or somewhat further up the cylinder wall and pointing obliquely upwards on the side of the cylinder remote from the air inlet valve 10, as shown in Figure 4. In either case the hydrogen enters the cylinder in a direction which makes an acute angle with the direction of the swirling air adjacent to the hydrogen injection pipe, and consequently the hydrogen mixes intimately with the air in a minimum of time.

Referring now to Figure 2, the air inlet valve 10 is situated in the cylinder wall 14 and its axis is horizontal but obliquely placed so that when produced it does not intersect the axis of the cylinder 14 but passes well to one side of it. Thus, air entering the cylinder through this valve forms a horizontal swirl rotating in the clockwise direction within the cylinder. In this case the hydrogen injection pipe 16 is situated in the cylinder wall and is arranged horizontally but directed obliquely as shown, so that the direction in which the hydrogen enters the cylinder makes an acute angle with the direction in which the air is swirling in the immediate neighbourhood of the hydrogen injection pipe.

Figure 3 illustrates one example of an engine in which the air enters in such a way that no definite circulation or swirling motion is set up. The air inlet valve 10 is in this case in the centre of the cylinder head and at the beginning of the compression stroke there is no definite circulation of air within the cylinder, and the velocity of any such circulation as there may be is small. In such a case the hydrogen injection pipe 16 is situated in the cylinder wall and is arranged to intersect the axis of the cylinder perpendicularly thereto. It is placed at a distance of about one-third of the piston stroke from the inner dead centre position, although this distance may vary from one-quarter to two-fifths of the stroke. This pipe need not, however, be perpendicular to the cylinder axis; if found more convenient it may be inclined obliquely to the cylinder axis towards the interior of the cylinder. If it is inclined upwardly its point of entry into the cylinder is placed lower than is stated above, whereas if it is inclined downwardly the point of entry

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is higher in the cylinder wall, so that in each case its axis intersects the axis of the cylinder between the limiting positions already mentioned.

As already stated, the injection of hydrogen, in forms of the invention such as are exemplified by Figures 1 and 2, occupies about 60° of the cycle, beginning at 220° (that is, 40° after outer dead centre) and ending not later than 280°, that is 80° before inner dead centre. In all such cases the hydrogen injection pipe opens immediately the air inlet valve has closed completely and it should remain open for at least 40° of the cycle. The pressure at which the hydrogen is injected in these cases may be about 1 atmosphere higher than the maximum pressure which the gases within the cylinder attain during the injection period. In cases such as are exemplified by Figure 3 the time during which the hydrogen injection pipe is open is substantially less than in the other cases (for example 30° of the cycle) and the pressure is substantially higher, for example 2 to 3 atmospheres above the maximum pressure within the cylinder during the injection period. Throughout the above description the word "air" is to be understood as signifying any mixture of oxygen with another gas or gases of an inert

nature; thus, instead of atmospheric air a mixture of oxygen and steam may be employed.

In Figures 1 and 3 of the drawings the exhaust valve is indicated at 18. In Figure 2 this valve is in the cylinder head and is therefore not shown. The sparking plug for igniting the compressed mixture of hydrogen, oxygen and inert gas is indicated at 20. As shown clearly in the drawings, the hydrogen injection pipe opens into the cylinder at that part of the cylinder wall traversed by the piston and above the lowest position of the piston.

I claim:

In an internal combustion engine, a cylinder, a piston of uniform diameter throughout reciprocable in said cylinder, said cylinder having a head at one end, valve means at the head end of the cylinder for supplying a mixture of oxygen and an inert gas, said valve means being flared to spread the entering gases and a hydrogen inlet pipe opening into said cylinder at a point traversed by the piston and spaced from the head end of said cylinder, said piston cutting off the inlet of said pipe.

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Sept. 22, 1964

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JET ENGINE PROCESS USING HYDROGEN PRODUCED FROM  
METAL-HYDROCARBON MIXTURE AND WATER  
Filed Nov. 1, 1962

FIG. 1

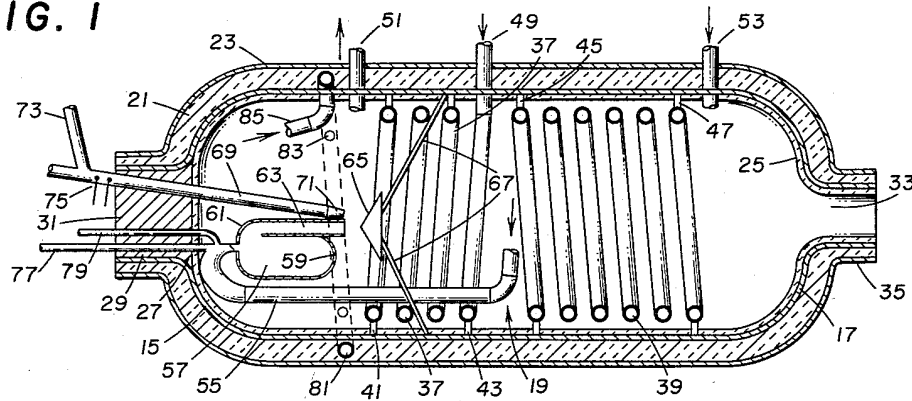


FIG. 4

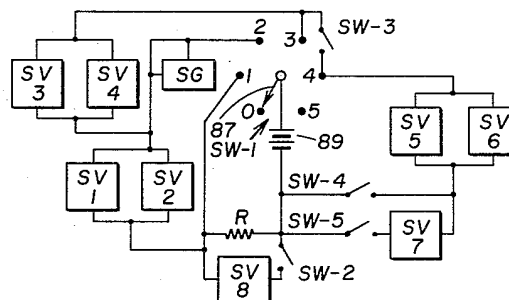


FIG. 2

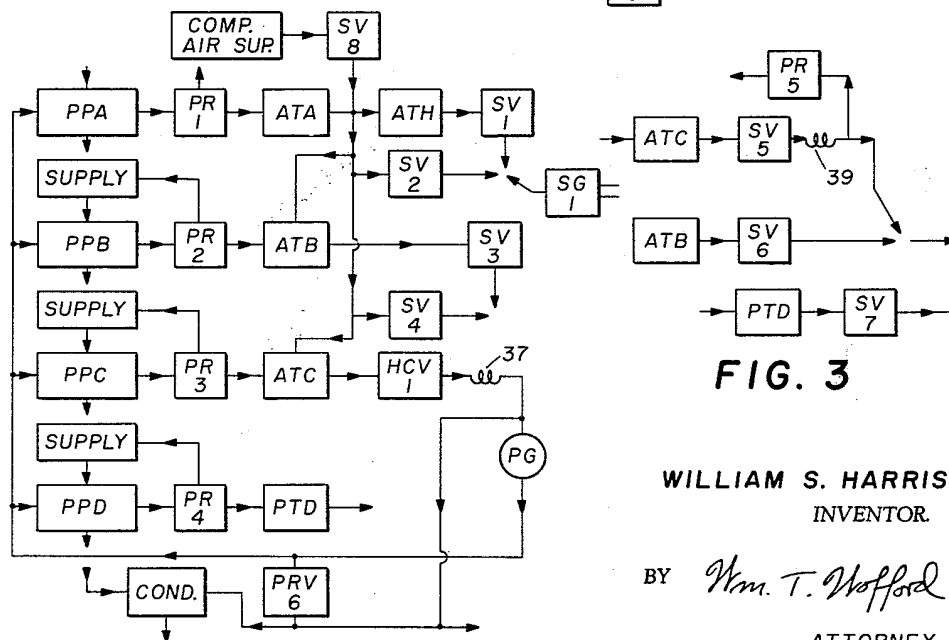


FIG. 3

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## JET ENGINE PROCESS USING HYDROGEN PRODUCED FROM METAL-HYDROCARBON MIXTURE AND WATER

William S. Harris, 911 Lynda Lane, Arlington, Tex.

Filed Nov. 1, 1962, Ser. No. 234,697

8 Claims. (Cl. 60—35.4)

My invention relates to jet engines and more particularly to unaspirated jet engines.

Engines of the internal combustion type have been most generally used in the past and even now to power aircraft. These engines, as is well known, burn a mixture of a hydrocarbon fuel and air. The gas pressure developed thereby moves pistons or turbines connected to one or more propellers, or produces a reactive forward thrust. Because these internal combustion type engines depend upon air for combustion of the fuel, it is recognized that their capabilities are limited at higher altitudes where the air is rarefied. So far it has been found impractical to carry, as part of the load aboard such aircraft, sufficient oxygen, or other substance, that will aid combustion and produce more power at the higher altitudes. There has developed, therefore, a need for an unaspirated engine; one that does not depend upon air in order to develop its fullest capabilities. Such an engine would be readily adaptable for use in an aircraft that is otherwise capable of flying at practically any altitude, but is presently limited because of the type of engines available.

Accordingly, it is the general object of the present invention to provide an improved jet-type engine that is not dependent upon air for the development of power.

Another object of the invention is to provide an improved unaspirated jet-type engine that develops power from internal chemical reactions.

In accordance with the principles of my invention, an unaspirated jet-type engine includes a generally tubular casing, a front end closure member and a rear end closure member, which, together, define a chemaction chamber. The rear end closure member has a rearwardly disposed axial thrust opening. Within the chemaction chamber there is provided a mixing chamber having inlet and outlet openings. Fluid conduits connect such inlet opening with a basic fuel supply and a supply of steam. The basic fuel and steam mix in the mixing chamber; the basic fuel being partially volatilized and reacting partially with the steam. Upon emerging from the mixing chamber, the steam and basic fuel impinge upon a previously heated diffuser-igniter plate and complete their reaction, producing hydrogen gas and an oxide of metal. A controllable quantity of oxygen is thereafter introduced into the chemaction chamber, and the oxygen reacts with the hydrogen to develop heat and other gases which emerge from the rearwardly disposed axial opening. An imbalance of internal forces results which produces a forward thrust.

For a further understanding of my invention and further objects and advantages thereof, reference may be made to the following description taken in conjunction with the accompanying drawing in which:

FIG. 1 is a schematic longitudinal sectional view of the engine in accordance with a preferred embodiment of my invention;

FIG. 2 is a schematic diagram of a portion of the power system of the engine in accordance with a preferred embodiment of my invention;

FIG. 3 is a schematic diagram of another portion of the power system of the engine in accordance with a preferred embodiment of my invention; and

FIG. 4 is a schematic diagram of electrical controls pertaining to the system of FIG. 2.

Referring now to FIG. 1, an engine 11 comprises a cylindrical casing 13, having a longitudinal axis. The front end of the casing 13 is closed by a front end closure head 15 and the rear end by a rear end closure head 17. The space within the casing 13 and between the closure heads 15, 17 is designated generally as a chemaction chamber 19. For convenient reference herein, the right end of the engine, as viewed in FIG. 1, is designated the rear end; the left end of the engine as the front or forward end.

The casing 13 is made preferably of high tensile steel, but, of course, other suitable materials may be used. A layer of insulation 21 surrounds the exterior of both the casing 13 and the heads 15, 17, and a thin sheet of high tensile steel is placed over the insulation 21, thereby forming a protective jacket 23. The interior surface of both the casing 13 and the closure heads 15, 17 is covered with a layer of a suitable heat resistant ceramic material, preferably one that may be bonded to the steel surfaces. It will be recognized of course that other suitable heat resistant materials may be applied to the inner surfaces if desired. The front end closure head 15 is dished and is provided with an axial opening 27. An extension neck 29 is attached to the closure head 15, so as to be in axial alignment with the casing 13 and to merge with the closure 15 at the opening 27. The extension neck 29 is closed and sealed preferably by a steel plug 31 fixed therein, or it may be closed in any suitable manner using other appropriate materials. A plurality of passages are provided in the plug 31, in each of which there is a tube or pipe. Each tube or pipe will be identified and its function described hereinafter.

The rear end closure head 17 is generally similar to the front end closure 15. The closure head 17 has an axial opening 33 and an extension neck 35 which is attached to the closure 17 so as to be in axial alignment with the casing 13 and to merge with the closure 17 at the opening 33. The neck 35, which is a thrust outlet, has a generally cylindrical form, as shown in FIG. 1. In a preferred embodiment of the invention the diameter of the neck 35 is determined experimentally so that the engine 11 will develop the maximum overall efficiency.

Within the chemaction chamber 19, there are two sets of coils of tubing; a primary coil 37 and a secondary coil 39. The primary coil 37 is situated just slightly in front of the mid-length point of the casing 13 and the secondary coil 39 is situated just to the rear of the mid-length point of the casing 13. Each coil of tubing 37, 39 is conveniently supported at several points around the periphery of the casing 13 by a plurality of hangers 41, 43 and 45, 47. The hangers 41, 43 and 45, 47 are thin plates which are welded preferably to both the tubes and the casing wall, but, of course, any other suitable coil-supporting device may be used. The primary coil of tubing 37 is connected to an inlet tube 49 and an outlet tube 51, both of which extend through the casing 13 and beyond the jacket 23. The secondary coil of tubing 39 is connected both to an inlet tube 53 which extends through the casing 13 and beyond the jacket 23, and to an outlet tube 55. The outlet tube 55, however, extends within the casing 13 toward the front end closure head 15 and connects with one of the tubes extending through the plug 31, for a purpose that will be described hereinafter.

A mixing chamber 57, having a longitudinal axis parallel to the axis of the casing 13, is located within the chemaction chamber 19, preferably between the primary coil 37 and the plug 31. The mixing chamber 57 is a generally hollow cylindrical body having a hemispherical dished head 59 at the rearward end and a flattened dished head 61 at the front end. A tube 63, having its axis sub-

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stantially parallel to the axis of the chamber 57, merges therewith and forms an outlet from the mixing chamber.

A hollow conical diffuser-igniter 65 is supported in a fixed location in the chemaction chamber 19 by a plurality of braces 67. The braces 67 are fixed to the diffuser-igniter 65 and to the wall of the casing 13 by welding, or in any other suitable manner. The axis of the diffuser-igniter 65 is aligned with the axis of the outlet tube 63 and the apex thereof is spaced slightly to the rear of the end of it. The diffuser-igniter 65 is made preferably of high tensile steel, or other suitable material, having an appropriate ceramic material bonded to its exterior surface. If desired, a high tensile heat resistant steel may also be used.

It was mentioned hereinbefore that a plurality of tubes enter the chemaction chamber 19 through passages in the plug 31. The tubes are received tightly and sealingly by each respective passage so as to prevent the escapement of gases from the chamber 19. One such tube 69 is disposed in an angularly sloping manner toward the axis of the mixing chamber 57. The end of the tube 69 nearest the chamber 57 is fitted with a starting nozzle 71. The nozzle 71 is located adjacent the end of the tube 63 for a purpose that will be explained hereinafter. The other end of the tube 69 extends from the plug 31 and joins a tube 73 of the power system, the purpose of which will be explained hereinafter. A high-tension type spark gap 75 is located within the tube 69 intermediately the plug 31 and the juncture of the tubes 69 and 73. The purpose of the spark gap will also be explained hereinafter. Another tube 77 extends through the plug 31 and the inner end of it is joined communicatively to the flattened dished head 61 of the mixing chamber 57. As mentioned previously, the tube 55 joins the tube 77 between the mixing chamber and the plug 31. Another tube 79, which is disposed in generally parallel spaced relation with respect to the tube 77, extends through the plug 31 and joins the tube 77 in the region of the juncture of the tubes 77 and 55. The purpose of the tubes 77, 79 will also be explained hereinafter.

A tube 81 encircles the outer surface of the casing 13 and is disposed in the insulating layer 21 close to the surface of the casing 13. This tube 81 has a plurality of fluid injection nozzles or orifices 83 which pierce both the casing 13 and the ceramic lining 25. The orifices 83 are so made that the amount of fluid passing each nozzle may be carefully regulated and controlled for a reason to be explained hereinafter. One end of the tube 81 is sealed (not shown) and the other end connects to apparatus of the power system. The axis of each nozzle 83 is directed angularly toward the region of the chemaction chamber 19 that is between the end of the outlet tube 63, focusing on the apex of the diffuser-igniter 65. The purpose of the tube 81 and the fluid injection nozzles 83 will be explained hereinafter.

The power system illustrated schematically in FIG. 2, includes a starting system and an auxiliary power system. The main power system is illustrated in FIG. 3.

The starting power system includes an air pump, PPA, four pressure tanks, ATA (air), ATB (basic fuel), ATC (water) and ATH (gasoline), a source of compressed air, the solenoid valves SV-1, SV-2, SV-8 and a spark gap, SG-1.

The auxiliary power system includes among other things a basic fuel pump, PPB; a water pump, PPC; and an oxygen pump, PPD. Each of these pumps is connected to a source of "Supply" and the discharge therefrom, including pump PPA, is connected via respective relief mechanisms PR1, PR2, PR3 and PR4 to the tanks ATA, ATB, ATC and PTD. Other equipment of the auxiliary power system includes a primary coil 37; a pressure actuated valve, PG-1; a heat regulated control valve, HCV-1; a pressure relief valve, PR-6; and a condenser, "Cond." The solenoid valves SV-3 and SV-4 are also included in the auxiliary power system. The auxiliary power sys-

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tem is, of course, a part of the overall power system and its function will be described hereinafter.

The main power system, as seen in FIG. 3, includes the secondary coil 39, a pressure relief mechanism, PR-5, the oxygen tank PTD, the solenoid valves SV-5 to SV-7 inclusive, and the tube 81 with its fluid injection nozzles 83. The function of the main power system will be described hereinafter.

FIG. 4 illustrates schematically the electrical controls for the power system of FIGS. 2 and 3. A main throttle is provided which includes a multi-position switch, SW-1. Other switches SW-2 to SW-5 inclusive are connected, for a purpose to be explained hereinafter, in circuitry with the solenoid valves SV-1 to SV-8 inclusive and the high-tension spark gap SG-1.

Now in order to describe the operation of the engine 11 reference is made to the figures of the drawing.

Prior to commencing operations which start the engine and bring it up to a desirable power level, it is necessary that there be available a supply of basic fuel, water, oxygen, gasoline and compressed air. The fuel which I designate as basic fuel and which I prefer to use in the engine of my invention is a quantity of a metal, in a finely divided or powdered form, mixed with a liquid hydrocarbon. The metal that I have selected is magnesium, although other suitable metals may be chosen from the activity list of metals. Magnesium is preferred, principally because it is readily available, it reacts desirably with steam or hot water to produce a great amount of heat, and it is less expensive than the other more active metals. It is readily appreciated that the metal should be in finely divided particle or powdered form because, in such form, more surface area is presented for reaction with other materials, as will be explained hereinafter. It is desirable to suspend the metal in a liquid hydrocarbon because both are compatible and there is no reaction between them. A hydrocarbon liquid is inert with respect to the metals of the activity list. Moreover, the hydrocarbon liquid is a satisfactory vehicle to carry the powdered fuel via the pump and tubing of the power system to the mixing chamber 57 as will be explained hereinafter. I prefer to use the liquid hydrocarbon kerosene because it is readily obtainable, inexpensive and combustible. Combustibility of the hydrocarbon liquid is a desirable property, the importance of which will be hereinafter pointed out.

In a preferred embodiment of my invention, the starting system exists separate and apart from the auxiliary and main power systems. The starting system is used only in starting and is not essential to sustain the operation of the engine, after it begins to generate thrust. In some applications, the units of the starting systems may be conveniently placed on a structure that can be moved from one location to another. This is particularly advantageous because a single starting system then may easily and readily serve more than one engine of my invention. Yet, in some other applications, it may be more desirable to incorporate the units of the starting system into the structure to which or within which the engine is attached.

Initially the normally-closed solenoid valves SV-1 to SV-8 inclusive are closed and a throttle lever 87 of the throttle switch SW-1 is in the off or zero position. Now, to commence operations, move the throttle lever 87 to position 1, and at the same time close switch SW-2 either manually, or in some other appropriate manner. The solenoid valve SV-8 opens and compressed air flows from the supply source, "Comp. Air Supp." to the tanks ATH (gasoline), ATB (basic fuel) and ATC (water). The gasoline and basic fuel are forced by the air pressure from the tanks ATH, ATB up to the solenoid valves SV-1 and SV-2. The water in tank ATC moves up to the heat controlled valve HC-1, which operates thermostatically under the influence of temperature.

The next step is to move the throttle lever 87 to position "2," which then causes the solenoid valves SV-1

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and SV-2 to open; the valve SV-8 remaining open. Upon the opening of valves SV-1 and SV-2, gasoline flows in the tube 73 and air enters the tube 69. The quantities of gasoline and air are, of course, controllable so that an ignitable mixture results. When an ignitable mixture is present in the tube 69, voltage is impressed by any suitable means and manner across the spark gap SG-1 and the gasoline-air mixture is ignited and burns, a flame appearing and being maintained at the end of the starting nozzle 71 adjacent the tube 63. The flame at the starting nozzle 71 heats both the end of the tube 63, which is also the main nozzle, and the diffuser-igniter 65. It is desirable at this stage of the operating procedure to pause a few seconds to allow sufficient time for the flame to preheat the diffuser-igniter 65; whereupon the throttle lever 87 is moved to position "3."

With the throttle lever in position "3," the solenoid valves SV-1, SV-2 and SV-8 remain open; the flame at the starting nozzle continues to burn; and the solenoid valves SV-3, SV-4 now open. The basic fuel enters the tube 77 via SV-3 and air from the tank ATA enters the tube 79 via SV-4. The basic fuel and air enter the mixing chamber 57 and are thoroughly intermixed therein by virtue of the high-turbulent nature of the chamber 57. The basic fuel and air mixture emerge from the main nozzle 63 and are ignited by the starting nozzle flame and burn.

The flame of the basic fuel and air heats the primary and secondary coils 37, 39. As soon as the temperature in the primary coil 37 is high enough to cause water to flash into steam, the valve HCV-1 opens. A controllable amount of water then enters the primary coil 37 and immediately flashes into steam. The amount of steam will be regulated, preferably, by controlling the amount of water entering the coil. The steam pressure continues to build up until it reaches a predetermined pressure at which the valve PG-1 opens. Steam then flows via suitable tubing or pipes, shown diagrammatically in FIG. 2, to the inlet of each pump PPA, PPB, PPC and PPD. These pumps are, preferably, positive displacement pumps of the plunger and piston type, but other types may be found suitable. In some applications it may be desirable to include in the auxiliary power system a pressure relief mechanism, PR-6 and a condenser, "Cond." The mechanism PR-6 will bypass steam to the condenser, should the pressure in the steam line become excessive and the condenser, of course, recovers condensate and conserves the water supply. If desired, an electric-power turbo-generator may be incorporated in the auxiliary power system, as well as an air compressor, and other like equipment. It is to be clearly understood that the usual pressure regulators, safety valves, feedwater heaters and the like equipment are included in the auxiliary power system to make it completely functional. The steam now operates the pumps PPA, PPB, PPC and PPD to move basic fuel, water and oxygen from the respective supply sources, and air from the atmosphere, into the auxiliary and main power systems.

As soon as the pump PPA establishes sufficient air pressure in the tank ATA, the switch SW-2 may be opened. The solenoid valve SV-8 then closes and stops the flow of air from the compressed air supply source. The next step in the operating procedure, is to move the throttle lever 87 to position "4," and to close switch SW-3. It is evident that valves SV-1 and SV-2 remain open and the flame continues to burn at the starting nozzle 71. Valves SV-3 and SV-4 remain open and so the basic fuel and air continue to mix in the chamber 57 and burn at the main nozzle 63. Steam is being generated in the primary coil 37 and is being led to the pumps, which are working normally. The next step is to close switch SW-4.

Valve SV-5 opens to admit water into the secondary coil 39 and valve SV-6 opens to admit basic fuel into the tube 77. It will be readily understood that the flames

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at the nozzles 71 and 63 generate sufficient heat in the secondary coil 39 so that when water is admitted thereto via SV-5, the water immediately flashes into steam. The steam flows from the secondary coil 39 via tubes 55, 57 to the mixing chamber 57. As soon as a steady flow of steam is established, the switch SW-3 is opened and the valves SV-1 to SV-4 inclusive close. The flame at the starting nozzle 71 is extinguished and the burning mixture of air and basic fuel is also extinguished. However, the basic fuel is not cut off as it continues to flow via valve SV-6 into the mixing chamber 57. The steam and the basic fuel thereafter mix in the mixing chamber 57. The metal of the basic fuel reacts partially with the steam and the liquid hydrocarbon of the basic fuel is volatilized by the steam. Thereafter, the mixture of steam, metal, volatilized liquid hydrocarbon, and the products of the partial reaction emerge from the main nozzle and impinge upon the heated diffuser-igniter 65 which causes the steam to react completely with the metal of the basic fuel producing an oxide of the metal and hydrogen. In a preferred embodiment of my invention the metal is magnesium, and so magnesium oxide and hydrogen are formed. The steam reacts also with the volatilized liquid hydrocarbon; the oxygen of the steam combining with the carbon of the liquid hydrocarbon to form carbon monoxide and more hydrogen. It is quite evident that the engine is now generating power without an air supply. The power is developed by internal chemical reactions and the engine no longer needs nor depends on the starting air and gasoline system. Hence, it is desirable to be able to cut off the units of this system and in most cases remove them. This is particularly desirable whenever the engine is used to propel an object through the air or in space. It will be recognized that by removing the starting system there will be less non-useable static weight which has to be propelled, and it is therefore possible to carry additional useable basic fuel or other materials.

The fact that magnesium reacts with steam to produce hydrogen and magnesium oxide is readily substantiated by reference to recognized texts concerning chemistry. A representative reference text is "Fundamental Chemistry" by Horace G. Deming, published by John Wiley & Sons, Inc., New York, N.Y., 1940.

Now, at this stage in the operation of the engine, the metal of the basic fuel is reacting with the steam and is producing a metal oxide and hydrogen. The steam also is reacting with the liquid hydrocarbon and is producing carbon monoxide and hydrogen. The reaction of the metal and steam is exothermal, liberating great quantities of heat. The hot gases produced in the chamber 19 develop an internal pressure on the casing 13 and when the gases emerge therefrom via the axial opening 33 and neck 35, a forward thrust is developed.

It will be recognized that we now have an engine that is developing considerable thrust power and is operating without using air. The engine is, at this stage, a hydrogen generating machine. The engine, however, is not developing all of the power that may be obtained from it. For, I have found that the hydrogen may be combined with a small amount of oxygen to produce much more power than has been generated so far by the reaction of the basic fuel and steam, and the steam and the liquid hydrocarbon. Hydrogen readily combines with oxygen to produce water vapor and large quantities of heat. However, it is recognized that hydrogen and oxygen combine readily in a vigorous reaction, and that there is a danger of an explosion should too much oxygen be mixed at one time with the hydrogen. Accordingly, it is essential that the amount of oxygen entering the chamber 19 via the nozzles 83 be very carefully controlled and metered. It is clear, then, that by this means both the violence of the reaction and the power level of the engine are variably controlled.

The oxygen is normally stored at high pressure in a

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suitable container, "supply" of FIG. 2, and is led to the oxygen pump PPD via a pressure regulator (not shown). The oxygen then is pumped to the receiver tank PTD via a pressure relief mechanism PR-4 and from the tank PTD to the solenoid valve SV-7. It is desirable to inject the oxygen at or above the pressure within the chamber 19 and it is also essential to carefully meter the amount injected. Thus, the purpose of the fluid injection nozzles is to meter a variable controllable quantity of oxygen as explained. When it is desired to inject the oxygen into the chemaction chamber, the switch SW-5 is closed and the valve SV-7 opens allowing a variable controllable amount of oxygen to pass through the nozzles 83 into the chemaction chamber 19.

The reaction of the steam with the liquid hydrocarbon is endothermal and the reaction of the steam with the metal is exothermal. The net amount of heat generated by these simultaneous reactions is highly exothermal. The amount of heat may be determined by referring to recognized sources of information. Some typical sources are, "National Bureau of Standards, Circular 500" published by the National Bureau of Standards of the U.S. Department of Commerce; and "Flames, Their Structure, Radiation and Temperature," second edition, by authors Gaydon, A. G., and Wolfhard, H. G., published by Chapman & Hall, Ltd., London, 1960.

The gases produced by the reaction of the oxygen and hydrogen develop additional internal pressure within the casing 13. All of the gases emerging from the axial opening 33 and the extension neck 35 produce an internal imbalance of forces and a thrust tending to urge the engine in the forward direction. It will be clear that the size of the thrust opening 33, in some measure, controls the pressure developed. It is evident that, if the thrust opening is too small, the pressure in the chemaction chamber would build up excessively. So, too, if the thrust opening is too large, the pressure within the chamber would be reduced and the speed of the gases emerging therefrom would be reduced; both situations tending to reduce the forward thrust. Thus, it is desirable to select a size of thrust opening 33 which is compatible with the size of the chamber 19, so that the engine develops power at its maximum efficiency. In order to obtain as much thrust power as possible, the reactions must be complete. The casing 13 and the chemaction chamber 19 thereof should be large enough to contain and adequately compress the gases produced, yet not so large that it becomes too heavy for practical useful purposes. It is recognized that compression of the gases within the chemaction chamber has a tendency to create more heat. This, too, increases the efficiency of the engine.

It will be recognized now that the engine of my invention develops maximum power without depending on a supply of air. This fact is quite significant, for the reason that while the engine of my invention employs air for starting purposes, the engine rapidly reaches a power level at which it becomes self-sustaining and from which it climbs without using air. Thus, once started, the engine of my invention is capable of generating full power thrust at the higher levels of space, where there is no atmosphere.

It is apparent then that I have provided a jet engine: that represents a significant advancement over the prior art jet engines; that develops its maximum thrust power independently of an air supply; that develops its power from internal chemical reactions which do not require air.

While I have shown my invention in only one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit thereof.

I claim:

1. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into said chemaction chamber powdered magnesium; injecting into

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said chemaction chamber steam to react with said magnesium and produce magnesium oxide and hydrogen; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; and exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

2. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into said chemaction chamber fuel comprising a mixture of finely divided particles of magnesium and a liquid hydrocarbon; injecting into said chemaction chamber steam to react with said fuel and produce hydrogen and an oxide of said active metal; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; and exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

3. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into said chemaction chamber fuel comprising a mixture of finely divided particles of magnesium and a liquid hydrocarbon; injecting into said chemaction chamber steam to mix with said fuel; raising the temperature of the mixture of said steam and fuel to accelerate a reaction thereof whereby hydrogen gas is produced; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; and, exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

4. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into said chemaction chamber fuel comprising a mixture of an active metal and a liquid hydrocarbon, said active metal being selected from a group of metals which react with a form of water to produce hydrogen and an oxide of said metal; injecting into said chemaction chamber steam to react with said fuel and produce hydrogen and an oxide of said active metal; injecting into said chemaction chamber variable controllable amounts of oxygen to react with said hydrogen and produce hot gases; and exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

5. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into said chemaction chamber fuel comprising a mixture of finely divided particles of an active metal and a liquid hydrocarbon, said active metal being selected from a group of metals which react with a form of water to produce hydrogen and an oxide of said metal; injecting into said chemaction chamber steam to react with said fuel and produce hydrogen and an oxide of said active metal; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; and exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

6. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into said chemaction chamber fuel comprising a mixture of finely divided particles of an active metal and a liquid hydrocarbon, said active metal being selected from a group of metals which react with a form of water to produce hydrogen and an oxide of said metal; injecting into said chemaction chamber steam to react with said fuel and produce hydrogen and an oxide of said active metal; raising the temperature of the mixture of said steam and fuel to accelerate a reaction thereof whereby hydrogen

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gas is produced; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; and exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

7. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into an isolated environment within said chemaction chamber fuel comprising a mixture of finely divided particles of magnesium and a liquid hydrocarbon; injecting into said environment steam to mix with said fuel; raising the temperature of the mixture of said steam and fuel to accelerate a reaction thereof whereby hydrogen gas is produced; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; utilizing said hot gases to generate said steam; and, exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

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8. In a jet engine having a chemaction chamber wherein there is an exhaust passage, the method of producing power thrust comprising the steps of: injecting into an isolated environment within said chemaction chamber fuel comprising a mixture of an active metal with a liquid hydrocarbon, said active metal being selected from a group of metals which react with a form of water to produce hydrogen and an oxide of said metal; injecting into said environment steam to react with said fuel and produce hydrogen and an oxide of said active metal; injecting into said chemaction chamber oxygen to react with said hydrogen and produce hot gases; utilizing hot said gases to generate said steam; and, exhausting the gases resulting from said reaction via said exhaust passage to impart a thrust to said engine opposite to the direction of said emerging exhaust gases.

#### References Cited in the file of this patent

#### UNITED STATES PATENTS

3,049,872      Johnson et al.      ----- Aug. 21, 1962

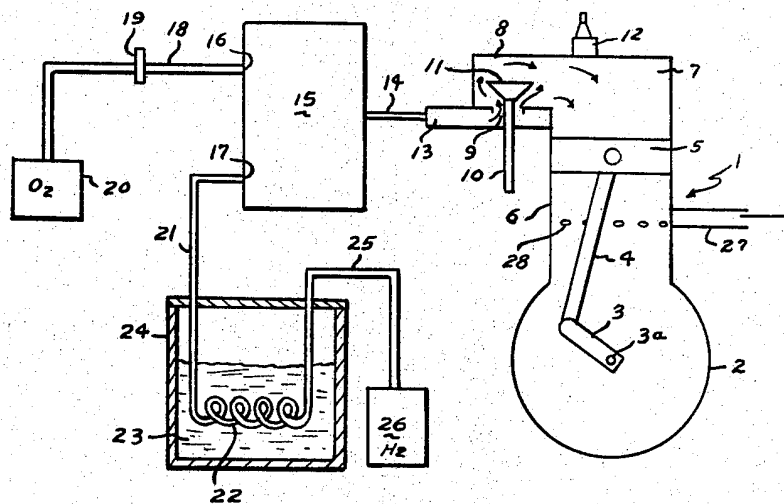
Oct. 7, 1969

R. E. QUIGLEY, JR., ET AL

3,471,274

HYDROGEN-OXYGEN FUEL INTERNAL COMBUSTION ENGINE

Filed Oct. 28, 1966



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# United States Patent Office

3,471,274

Patented Oct. 7, 1969

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## HYDROGEN-OXYGEN FUEL INTERNAL COMBUSTION ENGINE

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U.S. Cl. 48—180

5 Claims 10

### ABSTRACT OF THE DISCLOSURE

The present invention relates to internal combustion engines which operate with a fuel mixture of oxygen and hydrogen, and in which the mixture is cooled well below ambient temperature before being introduced into the combustion chamber.

The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without the payment to us of any royalty thereon.

Prior to this invention, oxygen and hydrogen have been introduced as a mixture into the combustion chamber through separate cam-operated valves. The result was that when these engines are operated according to the Otto cycle, they produce severe detonations. The combusted gas movements would tend to scrub the cylinder walls of the lubricant and cause over-heating of the combustion chamber walls. Backfiring of the charge through the manifold, caused by localized excessive heat zones in the cylinder walls may also be present, which gives rise to overheating of the valves. These heated spots often would cause premature igniting of the gases. From the operation standpoint, an engine of this character runs rough and uneven, is hard to start, and exhibits considerable loss of power.

These difficulties do not appear to lie in any variation from an optimum ratio between the hydrogen and the oxygen content or the compression ratio, but instead, appear to be due to a high flame speed within the combustion chamber.

Various proposals have been made to eliminate these dangerous backfirings, for example, it has been proposed to introduce flame arresters in the induction passage of the manifold. However, the pressure wave created by the blowback would hurl these arresters out of position. Increasing the hydrogen flow (thus enriching the mixture ratio) or the coolant water flow (which lowers head temperatures) appears to increase the missing effect of the engine drastically.

In accordance with our invention, we have discovered that this rate of flame speed can be reduced in a degree sufficient to provide satisfactory performance of the engine without the use of the aforesaid arresters or without requiring any critical ratio of the hydrogen to the oxygen.

An object of the invention is to provide an improved method and structure by which the flame speed can be controlled in an internal combustion engine utilizing hydrogen-oxygen fuel.

A more specific object is to provide an improved engine of the type mentioned and in which the combustion takes place evenly through the power generating portion of the cylinder, with no hot spots or backfiring of the explosions.

However, a more general object is to improve the operating characteristics of a hydrogen-oxygen engine by eliminating the various causes for departure from the ideal

Otto cycle law of constant volume combustion so as to provide a longer operating life and optimum power.

These objects are carried out in brief by introducing a cold and already mixed gas into the combustion chamber which tends to reduce the rate of the explosion of each charge and also to eliminate any localized heated zones in the walls of the chamber which would tend to increase the speed of the flame during combustion. This cold gas mixture is obtained apart from the engine by subjecting one of the propellants to a cryogenic heat sink and then combining the latter with the other gas to provide a very cold mixture of hydrogen and oxygen in the optimum proportions.

The invention will be better understood when reference is made to the following description and the accompanying drawing in which the figure shows, in diagrammatic form, the improved structure and method for attaining the results set forth.

In the figure, reference character 1 generally designates by diagram the outline of an automotive engine of well-known design. Only those parts of the engine are shown in detail which are concerned with the invention. It will be understood that the engine has the usual crank shaft, flywheel, timing gears and valve lifting levers, also a suitably positioned water jacket, water pump and oil pressure connections. The crankcase is indicated at 2 and a rotatable crank is shown at 3 which is secured to a crankshaft 3a. A rod 4 is connected between the crank to a pintle in a piston 5. The latter may have piston rings (not shown). The crankcase carries an upright cylinder 6 at the top position, the upper portion of which serves as a combustion chamber 7. The latter is provided with a horizontal rectangularly shaped extension 8 having an inlet opening 9 along the bottom surface. A stem 10, carrying an inlet valve 11 at the top, reciprocates in this opening. The valve has a tapered periphery which can fit snugly within a valve seat of similar shape and formed about the opening 9. The stem 10 is adapted to be moved vertically by a suitably positioned cam-operated rod (not shown) which is precisely timed by the usual gears. A spark plug 12 is threaded into the top of the combustion chamber. There is an opening in the lower wall of the manifold 13 which serves as a vertical support for the valve stem. The outer end of the manifold is closed except for an opening which receives a conduit 14.

A mixing tank, which could take the form of a carburetor in a standard engine is indicated at 15. This tank is provided with a pair of inlet openings 16, 17, the upper one of which leads by conduit 18 through an adjustable orifice device 19 of any suitable and well-known type to a source of oxygen 20. The latter is in the gaseous form and under high pressure. The lower opening 17 is connected through a conduit 21 to a coil 22 immersed in a bath 23 of liquid nitrogen contained in a closed tank 24. Well known provisions are provided to maintain an adequate filling of the liquid in the tank and also to vent the nitrogen gas. The other end of the coil is connected through a conduit 25 to a source of high pressure hydrogen 26 in gaseous form.

It is apparent that the oxygen and the hydrogen are caused to flow through their respective conduits into the tank 15 where these elements are combined as a homogeneous mixture. This mixture is caused to flow through the conduit 14 and manifold 13 when the valve 11 is lifted during the intake stroke of the piston. A four-stroke cycle engine can be advantageously employed, and assuming that the ignition at spark plug 12 has been properly timed through the usual type of gearing, combustion of the mixture will occur at practically constant volume (Otto cycle). Since the power stroke exists for only a part of the total time of the cycle, a flywheel (not shown) is used to smooth out the power pulses and so obtain, essen-

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tially, a uniform rotation of the crankshaft. A vacuum exhaust pump (not shown) is preferably connected to the exhaust pipe 27 to remove the products of combustion when the exhaust ports 28 are uncovered by the piston.

#### OPERATION OF THE IMPROVED GAS INTAKE

In accordance with our invention we supply the combustion chamber with a cold homogeneous mixture of hydrogen and oxygen in order to avoid the preignition problems and to reduce the flame speed such that there are no detonations present. The mixing operation is performed apart from the engine and specifically within the tank or pot 15 and at a pressure of preferably 153 p.s.i. gage. The tank can, of course, be structurally attached to the engine for manufacturing reasons. Essentially, it operates from the mixing standpoint entirely separate from the engine in order to assure a high degree of homogeneity before the fuel is introduced into the combustion chamber.

The oxygen at source 20 is in the gaseous form and at ambient temperature. The volume or rate of flow of the oxygen into the mixing chamber can be regulated at the orifice 19. The hydrogen source 26 is passed through a liquid nitrogen bath at the tank 24. The nitrogen is maintained at about  $-320^{\circ}$  F. and the hydrogen emerges from the tank at a temperature of about  $-300^{\circ}$  F.

After passing through the cooling device, the gas flows into the mixing pot 15 in order to be thoroughly mixed with the introduced oxygen. The gaseous mixture has a temperature in the preferred regime of  $-258^{\circ}$  F. or even colder depending on the ratio of oxygen to hydrogen as controlled by the orifice 19. It was shown during tests that the lower the input temperature of the gas mixture the greater decrease was obtained in the severity of detonations of the engine during operation.

The cold gas mixture, upon reaching the combustion chamber is at a cryogenic regime of less than  $-190^{\circ}$  F. at which temperature it tends to cool the walls of the chamber so as to eliminate any local hot spots which could bring on preignition. The cold condition of the gas definitely reduces the severity of detonation during combustion so that there is little or no backfire to ruin the valves by overheating. The overall result is that the engine operates quieter and has a longer operating life than the prior oxygen-hydrogen engine in which a mixture of gases is introduced into the combustion chamber at ambient temperature.

While a certain specific embodiment has been described, it is obvious that numerous changes may be made with-

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out departing from the general principle and scope of the invention.

We claim:

1. In the art of eliminating local hot spots in the explosion walls of an internal combustion engine which operates on a mixture of oxygen and hydrogen, the step of mixing the oxygen and hydrogen before introducing the fuel into the combustion chamber, and the further step of cooling one of the gases to a relatively low temperature prior to the mixing operation in order to introduce the gaseous mixture in a cold state into the combustion chamber.

2. The method according to claim 1 and in which the hydrogen content is cooled to the cryogenic regime of below  $-190^{\circ}$  F.

3. In an internal combustion engine operating on the combined explosive effect of oxygen and hydrogen, means for eliminating local hot spots in the walls of the combustion chamber during the explosion, said means including a tank external of the combustion chamber of the engine and within which the two gases are mixed for introduction into said chamber, means for cooling one of said gases to a temperature considerably below ambient temperature prior to forming the mixture whereby the mixture is introduced into the combustion chamber in a relatively cold state in order to reduce the rate of flame speed within the chamber.

4. Apparatus according to claim 3 and in which said cooling means operates only on the hydrogen component of the mixture.

5. Apparatus according to claim 4 and in which said cooling means operates to lower the temperature of the hydrogen prior to mixing to a temperature such that the temperature of the mixture will be less than  $-190^{\circ}$  F.

#### References Cited

##### UNITED STATES PATENTS

1,275,481	8/1918	Seymour.
3,232,050	2/1966	Robinson et al. ----- 60—36

U.S. Cl. X.R.

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U.S. Cl. X.R.

60—36; 123—1, 119



March 23, 1971

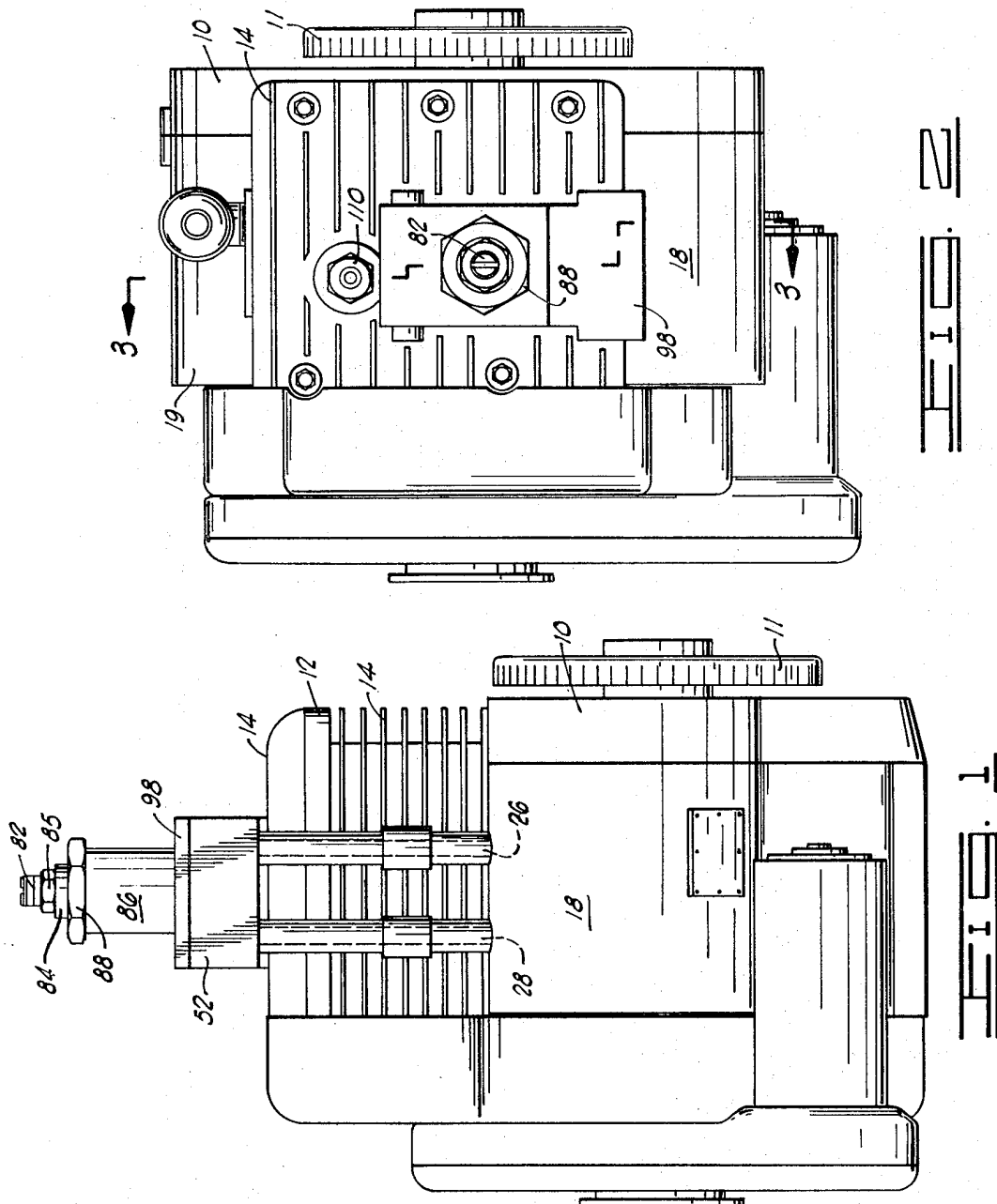
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3,572,297

HYDROGEN FUELED INTERNAL COMBUSTION ENGINE

Filed Jan. 26, 1970

4 Sheets-Sheet 1



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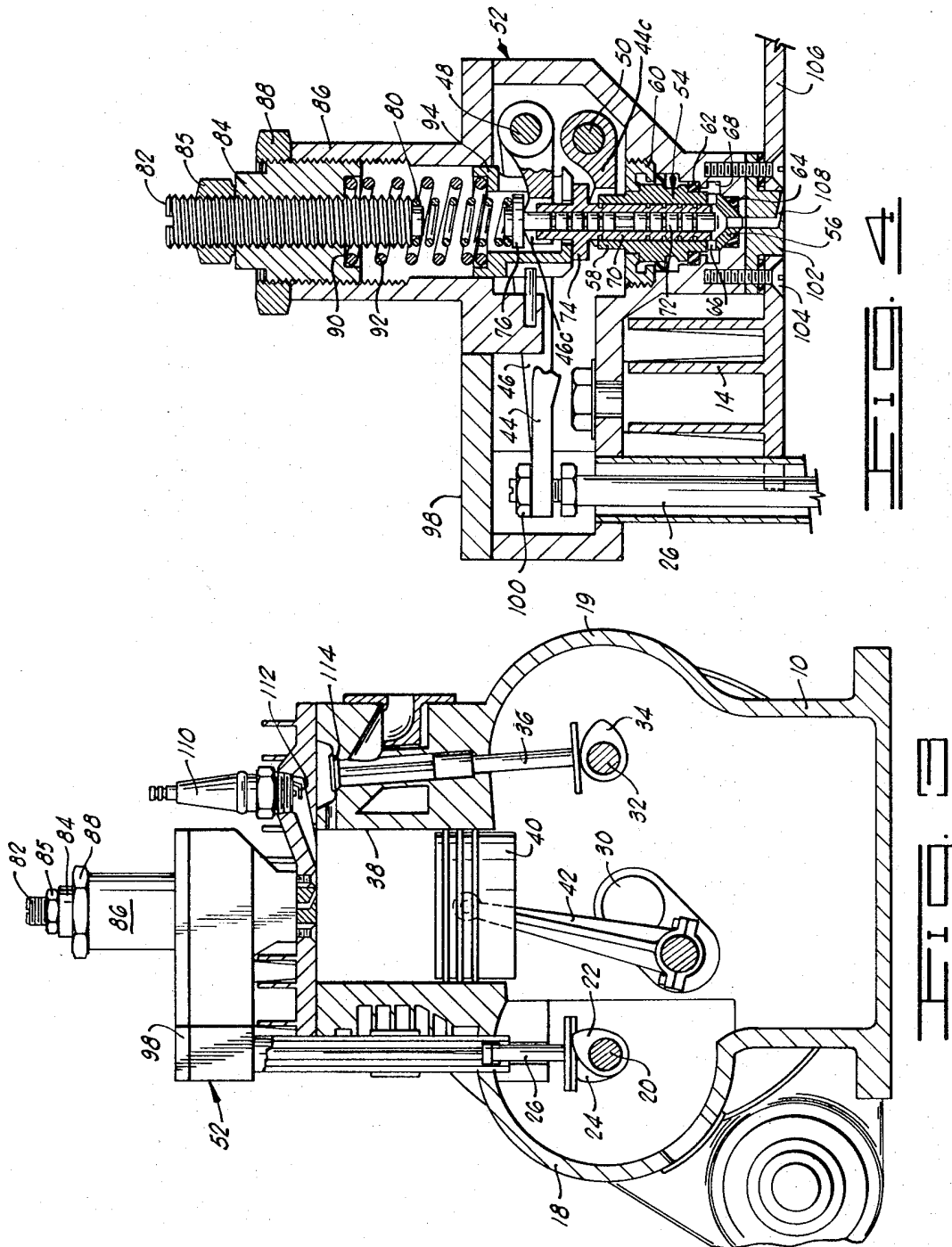
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3,572,297

HYDROGEN FUELED INTERNAL COMBUSTION ENGINE

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4 Sheets-Sheet 2



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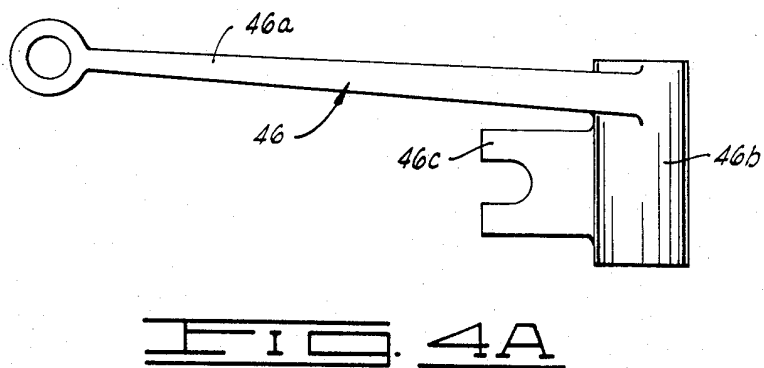
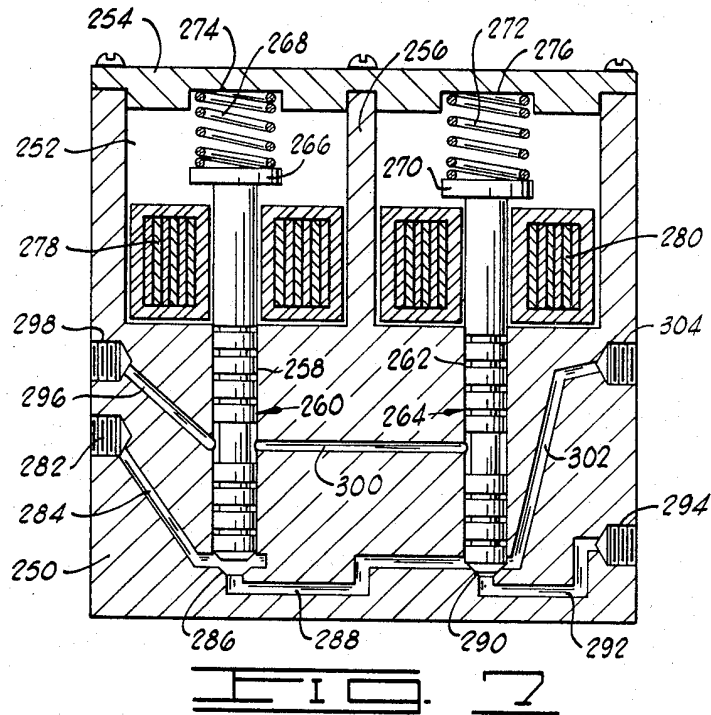
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3,572,297

HYDROGEN FUELED INTERNAL COMBUSTION ENGINE

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4 Sheets-Sheet 3



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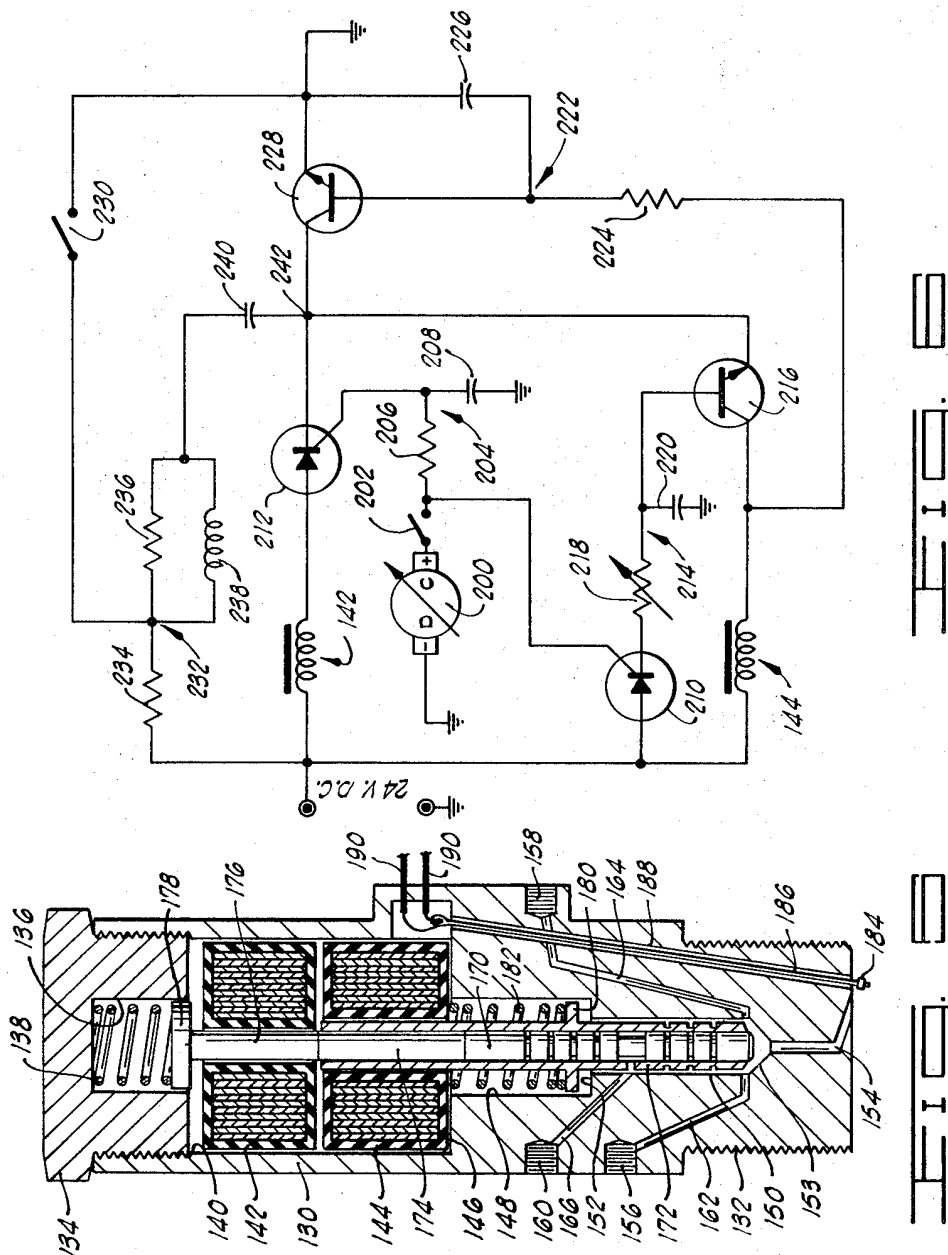
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3,572,297

## HYDROGEN FUELED INTERNAL COMBUSTION ENGINE

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4 Sheets-Sheet 4

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# United States Patent Office

3,572,297

Patented Mar. 23, 1971

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## HYDROGEN FUELED INTERNAL COMBUSTION ENGINE

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U.S. Cl. 123—1

21 Claims

### ABSTRACT OF THE DISCLOSURE

This invention relates to an internal combustion engine operated by direct injection of hydrogen into the cylinders thereof. Hydrogen is mixed with a portion of the air in the cylinders to form a combustible mixture which is ignited and burned concurrently with injection over a portion of the expansion stroke and in some cases a portion of the compression stroke. Dual poppet valves are used for injecting the hydrogen and are timed to open and close in response to sensed engine operating parameters.

### BACKGROUND OF THE INVENTION

#### Field of the invention

This invention relates to internal combustion engines operated by injection of a combustible gaseous fuel directly into the cylinders of the engine. In one more restricted aspect, the invention relates to injection valves useful for injecting hydrogen into the cylinders of internal combustion engines.

#### Brief description of the prior art

It has been heretofore proposed to fuel internal combustion engines with hydrogen gas. This fuel burns in air to yield water as the main product of combustion, and therefore fewer atmospheric contaminants result from its use under controlled conditions. By controlling the air-fuel ratio, relatively lower temperatures may be produced than when fossil fuels are employed.

The use of hydrogen as a fuel for internal combustion engines was demonstrated in the 1930's by the German engineer, Rudolph Erren. His work is epitomized in U.S. Pat. 2,183,674, U.S. Pat. 1,901,709, British Pat. 462,605, and British Pat. 364,180, and included a proposal for directly injecting hydrogen into the cylinders of the engine early during the compression stroke and terminating such injection not later than 80° before top dead center during the compression stroke (British Pat. 462,605). Erren's major operational problem and one that he was not able to overcome was detonation within the combustion chamber.

In the late 1940's, King, Wallace and Mahapatra at the University of Toronto worked with a co-operative fuel research (CFR) internal combustion research engine in studying the nuclear theory of ignition for various hydrogen-air mixtures over a range of pressure ratios. A hydrogen-air mixture was admitted to the cylinder through a carburetor. Unless frequent, regular and thorough schedules for cleaning the combustion chamber were set up, severe knocking due to detonation, and pre-ignition made it impossible to run the engine on any but the leanest mixtures and lowest compression ratios.

In 1963, the Vickers division of the Sperry Rand Corporation sought to produce a hydrogen fueled internal combustion engine for use with spacecraft. The Marquardt Corporation of Van Nuys, Calif., undertook a similar project. Both the Vickers and Marquardt projects utilized a mixture of hydrogen and oxygen with hydrogen serving as the working fluid and the engine exhausting into a vacuum. The use of substantially pure oxygen

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as the oxidizer was found to produce significantly increased thermal stress in the engine and led to severe corrosion, leakage and lubrication problems. In the Vickers and Marquardt engines, ignition delays and detonation occurred to an undesirable extent. Both projects were abandoned before a practical engine was developed.

### BRIEF DESCRIPTION OF THE PRESENT INVENTION

The present invention provides a practical hydrogen fueled internal combustion engine which, through the unique combined concepts of direct hydrogen injection, employment of air as the oxidizer, and igniting the hydrogen during its injection and sustaining the combustion over a specific range of the engine cycle, poses no significant problem of pre-ignition, detonation or excessive thermal stress. The engine differs from the previously known systems basically in how and when hydrogen fuel is injected and ignited, and in the oxidizer used to yield the combustible mixture. In another aspect, the inventive concepts herein disclosed encompass a novel fuel injector valve, and control devices used to optimize the actuation of this valve.

Broadly described, the present invention comprises a method of hydrogen fueling an internal combustion engine which includes the steps of passing air into the cylinder of the engine; injecting substantially pure hydrogen directly into the cylinder of the engine beginning the injection at a time which is between 60° and 0° before top dead center of the compression stroke, igniting the hydrogen immediately after the commencement of injection by means of a spark plug, hot wire (glow plug), hot air (compression ignition), or catalytically; continuing to inject hydrogen directly into the cylinder of the engine until between 0° and 90° after top dead center during the expansion stroke; and substantially concurrently with the direct injection of hydrogen, sustaining combustion of the hydrogen.

In a different aspect, the invention relates to the apparatus by which the described method is carried out, including an internal combustion engine having at least one cylinder, single or multiple poppet injector valves mounted on each cylinder for injecting hydrogen gas directly into the respective cylinder, and means for automatically controlling the opening and closing of the poppet valves in response to certain engine operating parameters and means for igniting said hydrogen gas. In one construction with dual poppet valves, the valves are coaxially and concentrically disposed and are each connected to valve stems which are individually actuated in timed sequence by a pair of sequentially energized solenoids to thus open the valves, and are returned to a position of closure by suitable spring elements after de-energization of the respective solenoids.

An important object of the invention is to provide a practical internal combustion engine with which atmospheric contamination resulting from engine operation is substantially reduced as compared to internal combustion engines now in use.

An additional object of the invention is to provide a practical internal combustion engine which does not employ fossil fuels in its operation. Non-fossil fuels, as hereinafter used, is defined as fuels excluding gasoline, kerosene and fuel oils.

A further object of the invention is to provide a hydrogen fueled internal combustion engine in which detonation and preignition are minimized.

Another object of the invention is to provide a hydrogen fueled internal combustion engine which is safer to operate than hydrogen fueled internal combustion engines previously built.

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Yet another object of the invention is to provide a hydrogen fueled internal combustion engine which does not become fouled as quickly, or require cleaning of the combustion chamber as frequently, as the engines of this type which have been previously proposed.

Another object of the invention is to provide a hydrogen fueled internal combustion engine which is characterized in having a relatively long and trouble-free operating life.

Additional objects and advantages of the invention will become apparent as the following detailed description of the invention is read in conjunction with the accompanying drawings which illustrate the invention as it relates to a single cylinder engine.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view of an internal combustion engine constructed in accordance with the present invention.

FIG. 2 is a plan view of the internal combustion engine depicted in FIG. 1.

FIG. 3 is a sectional view taken along line 3—3 of FIG. 2.

FIG. 4 is an enlarged, partially sectional, partially elevational view of one embodiment of a mechanically actuated dual poppet injection valve constituting a subassembly of the invention.

FIG. 4A is a detail plan view illustrating a rocker arm forming a portion of the mechanical linkage of the hydrogen fueled engine.

FIG. 5 is an enlarged, partially sectional, partially elevational view of a different embodiment of a dual poppet injection valve constituting a subassembly of the invention.

FIG. 6 is a schematic wiring diagram illustrating electrical circuitry utilized for controlling fuel injection in response to engine speed and engine loading.

FIG. 7 is an enlarged, partially sectional, partially elevational view of yet another embodiment of an injection valve assembly useful in the invention.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Referring initially to FIGS. 1, 2, and 3, shown therein is a single cylinder, L-head internal combustion engine. The engine includes a crankcase 10 having mounted thereon a cylinder head 12 carrying cooling fins 14. A crankshaft 30 extends through the crankcase 10, projects from opposite sides thereof, and has a vibration dampening flywheel 11 mounted on one of its ends. Protruding from opposite sides of the crankcase are a pair of cam shaft chambers 18 and 19. The cam shaft chamber 18 carries a dual lobed injector valve cam shaft 20 which has a pair of lobes 22 and 24 secured thereon for actuating a pair of push rod subassemblies 26 and 28 in a manner hereinafter described. The crankshaft 30 extending centrally through the crankcase 10 is drivingly connected to the cam shaft 20 by suitable gearing (not shown). The crankshaft 30 also drives through suitable gearing (not shown) a cam shaft 32 carrying cam lobes 34. The cam lobes 34 operate push rods 36 for opening and closing the intake and exhaust valves for admitting air and exhausting combustion products from the cylinder of the engine. The cylinder of the engine appears in FIG. 3 and is designated by reference numeral 38. The cylinder has slidably and reciprocally mounted therein a piston 40 which is driven from the crankshaft 30 by a crank arm 42 in a conventional manner.

The engine as thus broadly described is a commercially available four horsepower, four-cycle, one-cylinder, L-head engine which has been modified in its construction to accommodate the injection of gaseous hydrogen directly into the cylinder in accordance with the present invention. The structure which is utilized to accomplish such injection includes the push rod subassemblies 26 and 28 to which reference has hereinbefore been made. The push rod subassemblies 26 and 28 extend upwardly from the

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cam shaft 20 and are connected through a suitable ball joint connection, or other movement-facilitating connection, to rocker arms 44 and 46 (FIG. 4) disposed at the upper ends of the push rod subassemblies 26 and 28, respectively.

The rocker arms are similar in construction, and include elongated shaft portions 44a and 46a (FIG. 4A), respectively. Each of the rocker arms 44 and 46 has a sleeve portion 44b and 46b, respectively, at the end thereof opposite its end which is connected to the respective push rod subassembly 26 or 28, and the sleeves of the rocker arms are journaled on a pair of shafts 48 and 50 which extend between the walls of an injector housing designated generally by reference numeral 52. Extending in a reverse direction from the sleeve 44b and 46b and parallel to the shaft portions 44a and 46a, respectively, are bifurcated lifting plates 44c and 46c, respectively.

The rocker arms 44 and 46 function, in response to the rotation of the cam shaft 20, to sequentially operate the dual valves of a dual poppet valve subassembly designated generally by reference numeral 54. The dual poppet valve subassembly 54 includes a conically tapered valve seat 56 having a port through the apex or lower end thereof, with the seat being formed on the lower end of a sleeve 58 which has a central bore therethrough communicating with the hollow interior of the conically tapered seat, and aligned with the port through the seat. The sleeve 58 carries a shoulder which facilitates its location and retention in the injector housing 52 by means of a nut 60 which is threaded into a threaded portion of the injector housing, and bears against the shoulder on the sleeve 58 to retain the shoulder in position. Suitable elastomeric sealing elements 62 are provided between the injector housing 52 in the sleeve 58 to provide a seal around the sleeve, and an elastomer seal 64 is also provided between the conically tapered valve seat 56 and the injector housing 52 to provide a seal at this location. The sleeve 58 carries ports 66 which facilitate the entry into the interior of the sleeve of a gaseous fuel from a circumferential fuel injection passageway 68 which surrounds the sleeve in alignment with these ports.

Disposed within the bore through the sleeve 58 are a pair of concentric valve elements, these being referred to as an outer valve element 70 and an inner valve element 72. It will be perceived that the outer valve element is in the form of a sleeve surrounding the inner valve element 72, and that the outer valve element carries a flange 74 at the upper portion thereof which is engaged by the bifurcated lifting plate 44c of the lower rocker arm 44. The inner valve element 72 is an elongated shaft having a flange 76 at the upper end thereof which flange rests upon the lifting plate 46c of the upper rocker arm 46. The flange 76 also functions as an abutment or stop for the lower end of a return spring 80. The return spring 80 engages the lower end of an externally threaded spring retainer element 82 which is threaded into a spring retainer sleeve 84 having an axial, internally threaded bore therethrough for receiving the spring retainer 82. A nut 85 is utilized for retaining the spring retainer 82 at the desired location within the retainer 84.

The spring retainer sleeve 84 is threaded into a threaded bore formed in a spring cover 86, and is retained in this position by a suitable nut 88. It will be noted that the spring retainer sleeve 84 has a counterbore 90 formed in the lower end thereof and that this counterbore receives the upper end of a valve return spring 92 which extends downwardly therefrom and is coaxially located with respect to the valve return spring 80. The lower end of the valve return spring 92 projects into a counterbore formed in the upper end of a bridge element 94 which is slidably inserted in the bore through the spring cover 86, and which is bored to receive the upper end of the inner valve element 72. One side of the generally cylindrically shaped bridge element 94 is cut away or apertured to permit the lifting plate 46c of the rocker arm 46 to project into the interior of the bridge element, and engage the flange 76

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on the upper end of the inner valve element 72. At its lower end, the bridge element 94 carries an inwardly projecting flange which bears against the upper side of the flange 74 carried by the outer valve element 70. It will thus be noted that the bridge element 94 functions to transfer the bias of the valve return spring 92 to the outer valve element 70 so that, at such time as the lower rocker arm 44 is not functioning to lift and open the outer valve element 70, the valve return spring 92, acting through the bridge element 94, will force this valve element to be reseated. In the status of the valve illustrated in FIG. 4, both the inner valve element 72 and the outer valve element 70 are in the open positions as a result of being lifted by the rocker arms 44 and 46.

In concluding the description of the subassembly depicted in FIG. 4, it may be pointed out that a cover plate 98 is provided for covering a cut away portion of the injector housing 52 so that access may be had to locknuts 100 used for securing the push rod subassemblies 26 and 28 to the rocker arms 44 and 46, and to facilitate adjustment of the throws of the rocker arms in response to the rotation of the cam shaft 20. Also, bolted to the lower side of the injector housing 52 is an orifice plate 102 which is also bored to receive bolts 104 extended through the cylinder head 106 of the engine. It will be noted that the orifice plate 102 is provided with an orifice 108 which is aligned with an opening formed in the lower end of the injector housing 52, which opening is aligned with the port through the conically tapered valve seat 56. Thus, by the passageway thus formed, gaseous fuel may be injected through the orifice 108 in the orifice plate 102 into the cylinder in a manner hereinafter described in greater detail.

The engine illustrated is conventionally constructed to further include a spark plug 110 which has its contact elements 112 communicated with the combustion chamber at the upper end of the cylinder 38. There are also provided the conventional intake and exhaust valves for admitting air to the combustion chamber and exhausting combustion products therefrom. The air intake valve appears in FIG. 3 and is designated by reference numeral 114. As previously explained, this valve is opened and closed in response to the rotation of the cam shaft 32 acting through a suitable push rod subassembly 36. The exhaust valve is operated in similar manner.

#### OPERATION

In the operation of the engine depicted in FIGS. 1-4, atmospheric air is drawn into the cylinder 38 on the intake (induction) stroke in conventional fashion, with the valve 114 being opened in properly timed sequence by the action of the cam shaft 32. During or at the end of the compression stroke, the injection of compressed gaseous hydrogen fuel is commenced. As the cam shaft 20 is rotated, the lobe 22 biases the push rod subassembly 26 upwardly, resulting in the pivotation of the rocker arm 44 to open the outer valve member 70. Opening of the outer valve member 70 is timed to commence at some time relatively early in the compression stroke. As the outer valve member 70 commences to open, hydrogen gas under pressure passes this valve member and contacts the inner valve member 72 which is still closed at this time. As the cam shaft 20 continues to rotate the cam 24 lifts the push rod subassembly 28, to pivot the rocker arm 46 and open the inner valve member 72. The opening of the inner valve member 72 is timed to occur not earlier than 60° before top dead center of the compression stroke (120° after stroke turnaround at bottom dead center). Preferably, opening of the inner valve member 72 is commenced about 30° or less before top dead center.

With the opening of the inner valve member 72, pressurized hydrogen gas commences to flow into the cylinder 38. The ignition circuitry is arranged to energize the spark plug 110 at the time that hydrogen injection is commenced. Almost instantaneously, the combustible mixture of hy-

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drogen and air which is adjacent the opening of the orifice 108 through the orifice plate 102 will be ignited, and a jet of flame extending from the orifice outwardly into the cylinder will be developed. As the inner valve member 72 opens wider, a greater amount of hydrogen will flow into the cylinder, and the flame front in the combustion chamber of the cylinder will be enlarged, but the combustion will be continuous and uninterrupted. The time during the compression stroke at which the inner valve member 72 is opened is dependent upon its rates of opening and the speed with which ignition is initiated after the first instant of opening. It will be apparent to those skilled in the art that it is essential that no large magnitude force is developed by combustion in opposition to the continued upward movement of the piston 40 in completing the compression stroke. Thus, in optimum operation, ignition is effected just prior to, or at the time of the attainment of the top dead center position by the piston 40. The commencement of opening of the inner valve member 72 at the described time of 60° before top dead center (or more preferably, 30° or less) is based upon this consideration, and the lag time occurring between initial opening of this valve member, and the commencement of actual combustion of the fuel air mixture.

For any specific open time of the injector and any specific orifice diameter, the actual quantity of fuel injected into the cylinder is controlled by the injector inlet pressure, which is in turn controlled by an undisclosed pressure regulating device responsive to engine speed and loading conditions.

An important function of the dual poppet valve system is to permit the necessary high speed, rapid sequence opening and closing of access to the cylinder 38 to be efficiently achieved without malfunction and loss of proper timing due to mechanical or electrical time lags, and the necessity to adequately overcome and dissipate inertial forces. Thus, for example, before the inner valve member 72 can be fully opened, and then returned to a closed position by the return spring 80, the time at which hydrogen flow to the cylinder 38 should be terminated has passed. This problem is obviated by starting to close the outer valve element 70 before the inner valve member 72 has quite completed its opening movement—this, of course, being accomplished by proper dimensioning and relative orientation of the lobes 22 and 24 on the cam shaft 20. In order to accomplish this earlier closing movement of the outer valve element, it is necessary to open it earlier than the inner valve member 70, and therefore the need is present for the opening sequence hereinbefore described.

As to the time when the flow of hydrogen to the cylinder is terminated, this is made to occur by closure of the outer valve member 70 at a time not later than 90° after top dead center during the expansion stroke of the piston 40. Preferably, closure of this valve occurs before 60° after top dead center. Combustion of the hydrogen in the cylinder continues up until this time, and occasionally for a very short time interval following the cessation of injection. After closure of the outer valve member 70, the inner valve member 72 can be closed at any time, provided its closure is effected before commencing to open the outer valve member shortly after commencement of the next compression stroke. Closure of both valve members is, of course, effected by the respective valve return springs 80 and 92.

It is an important feature of the present invention that hydrogen injection is commenced late in the compression stroke and is continued into the expansion stroke, the optimum timing depending on flow conditions and engine parameters. Ignition is initiated as soon as possible after the commencement of injection, and combustion is maintained throughout the period of injection. By operating the engine in this manner and utilizing air as the combustion supporting material, pre-ignition and detonation are reduced, the combustion temperature is

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maintained at a reasonable level, and smooth and knock-free operation of the engine is obtained. Although the utilization of a dual poppet valve for fuel injection is not essential to successful operation of the engine, the two-valve design allows more response time for the several components of the valve system, thereby reducing stress on the parts of the valve, and extending the effective operating life of the engine.

#### DOUBLE POPPET VALVE SUBASSEMBLY

A preferred embodiment of the double poppet injector valve useful for the injection of hydrogen into each combustion chamber of an internal combustion engine in accordance with the present invention is depicted in FIG. 5. This double poppet valve includes a housing 130 which has, in the form shown, a threaded lower end portion 132 permitting the housing to be threaded into the cylinder head of an engine. Other suitable types of connector elements might be provided in lieu of the threaded connection. At its upper end, the housing 130 is internally threaded to receive a retainer cap 134. The retainer cap 134 has a bore 136 formed therein to receive a valve return spring 138.

The housing 130 has a large internal bore 140 in which are located a pair of electrically actuated solenoids 142 and 144. The solenoid 142 will be referred to as the inner valve solenoid, and the solenoid 144 will be referred to as the outer valve solenoid. The outer valve solenoid 144 rests on a shoulder 146 formed at the intersection between the bore 140 and a counterbore 148 in the housing 130. The counterbore 148 also communicates with a second counterbore 150 and a shoulder 152 is formed at the intersection of the two counterbores. At the lower end of the counterbore 150, a conically tapered valve seat 153 is formed, and the counterbore 150 communicates through the valve seat 153 with an injection orifice 154 formed through the lower end portion of the housing 130.

Formed in the side of the housing 130 is a high pressure hydrogen injection port 156, a purge port 158 and a leak port 160. The high pressure hydrogen inlet port 156 and the purge port 158 communicate with the lower end of the counterbore 150 adjacent the upper edge of the valve seat 153 through passageways 162 and 164, respectively, which are formed in the housing 130. At a medial location along the length of the counterbore 150, a passageway 166 communicates with this counterbore and places it in communication with the leak port 160.

Extending coaxially in the counterbores 148 and 150, and through the bore 140 are an inner valve 170, and an outer valve 172 which coaxially and slidably surrounds the inner valve. The inner valve 170 is connected through a spacer 174 to an inner valve spring follower 176. The inner valve spring follower 176 has a flange 178 located at the upper end thereof and bearing against the lower end of the valve return spring 138. The outer valve 172 has a flange 180 formed intermediate its length and positioned between the lower end of a valve return spring 182 and the shoulder 152 formed at the intersection of the counterbore 148 with the counterbore 150. The upper end of the valve return spring 182 bears against the lower end of the outer valve solenoid 144.

For the purpose of igniting the combustible gaseous mixture in the combustion chamber during operation of the engine, a glow plug 184 is provided adjacent the lower end of the housing 130, and is connected to a suitable electrode 186 which is surrounded by suitable insulation, and is extended through a small bore 188 formed in the housing 130. At the upper end of the bore 188, the electrode 186 is connected to suitable electrical leads 190 for providing the electrical current necessary to the energization of the glow plug 184.

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In placing into operation of the dual poppet valve depicted in FIG. 5, the fuel injection system is first purged by connecting an inert gas, such as nitrogen, to the high pressure hydrogen inlet port 156. The purged gas is vented through the purge port 158. After purging, the purge port 158 is closed by a suitable plug. A source of high pressure hydrogen gas is then connected to the high pressure hydrogen inlet port 156, the ignition device 184 is connected to a suitable ignition circuit and the inner and outer valve solenoids 142 and 144, respectively, are electrically connected to a timing circuit which will operate the solenoids in a manner to be described, and in timed sequence in synchronism with the stroke of the piston within the cylinder of the internal combustion engine.

At a time early in or before the beginning of the compression stroke of the combustion engine, the outer valve solenoid 144 will receive an electrical impulse from the control circuitry which is responsive to the engine speed, and the pulse is timed according to the stroke cycle of the engine. The development of a magnetic field in the outer valve solenoid 144 will cause the outer valve element 172 to open, thereby permitting the high pressure hydrogen to come under the influence of the inner valve element 170 which is, at this time, still closed. It should be pointed out that in operation, the opening of the inner valve element 170 will commence to occur at a time after the complete opening of the outer valve element, and that one of the main advantages of the dual poppet valve system utilized in the invention is to permit better control of hydrogen flow in properly timed sequence by the use of the dual valves which more precisely control the admission of hydrogen to the orifice 154, and the termination of flow of the gas therethrough. Near the end of the compression stroke, the inner valve solenoid 142 will receive an electrical impulse, and by the development of the magnetic field will cause the inner valve element 170 to open. The opening of both valves will then allow hydrogen to flow through the opened valves into the combustion chamber.

It will be noted that the orifice 154 injects the hydrogen into the cylinder at a point adjacent the ignition device 184. The result of injection at this point is to cause a jet of flame to be developed at the opening of the orifice into the cylinder at such time as a combustible mixture of hydrogen and air is there developed. This ignition is, as previously explained, timed to occur close to, or at the instant of, the upper dead center position during the compression stroke of the piston. The combustion then continuously occurs until hydrogen flow into the cylinder is cut off. Early in the expansion stroke of the piston, the current to the outer valve solenoid 144 is terminated by the control circuitry, and the other valve element 172 is closed by action of its valve return spring 182. Closure of the outer valve element 172 interrupts the flow of hydrogen to the combustion chamber, and complete flow of hydrogen is terminated somewhere at or near about 90° after top dead center of the piston stroke, or preferably before this position, depending on the power required of the engine. The current to the inner valve solenoid 142 can be terminated any time thereafter to permit the inner valve element 170 to be closed by its return spring 138. The only condition is that the inner valve element 170 be closed prior to the commencement of opening of the outer valve element on the next operating cycle.

As has been previously pointed out, the dual poppet valve design allows more time for each component of the valve assembly to respond to the electrical pulses, and the valves conjunctively effect commencement and termination of hydrogen injection in synchronism with the cyclic movement of the piston. Moreover, the use of the dual poppet valve design reduces stresses on the valve parts, and allows the time which is required for dissipation of inertial forces while still achieving opening and closing of hydrogen input to the orifice 154 at the required times.



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An electrical circuit which can be used for automatically controlling the energization of the inner and outer valve solenoids 142 and 144, respectively, is depicted in FIG. 6. The control effected by the circuit here shown is correlated to the engine speed and manifold vacuum, but it will be apparent that other parameters could be sensed by appropriate sensing elements, and the opening and closing of the dual poppet valve could be made to respond to variations in the magnitude of the sensed parameters. Circuits which have been previously proposed for sensing such parameters as manifold pressure, engine temperature, injection air temperature, engine r.p.m., and the like are depicted and described in U.S. Pats. 3,456,628, 3,240,191, and 2,918,911, and the teachings of these patents are incorporated herein by reference insofar as they provide guidelines toward the construction of suitable circuitry to control the dual poppet valves used for hydrogen injection in the present invention in response to various engine operating parameters.

In the circuit depicted in FIG. 6, a signal developed by an engine driven DC generator 200 is connected through a cam shaft switch 202 to the resistance-capacitance (R-C) time delay circuit 204 containing resistor 206 and capacitor 208. The output of the DC generator is also connected through the cam shaft switch 202 directly to a silicon controlled rectifier (SCR) 210. The time delay circuit 204 is connected to a silicon controlled rectifier 212 so that, after a time delay which depends upon the applied voltage (which in turn depends upon engine speed) and the values of the resistor 206 and the capacitor 208, the silicon controlled rectifier 212 is turned on, permitting current to flow through the coil of the inner valve solenoid 142. At this time, the outer valve solenoid 144 has already been energized and the outer valve element 172 is open. Energization of the inner valve solenoid 142 thus opens the inner valve element 170, and permits fuel flow into the cylinder to commence. At the instant that the cam shaft switch 202 is closed, the silicon controlled rectifier 210 is energized and a signal is supplied to an R-C time delay circuit 214 which in turn, after a time delay which depends on the applied voltage and the resistance of resistor 218 and the capacitance of capacitor 220, turns off a lower gate turn-off triode 216. The time delay circuit 214 includes a variable resistor 218 and the capacitor 220. The value of the resistor 218 is determined by engine manifold pressure (which in turn depends on engine power output) by suitable transducer mechanism (not shown) such that, for example, a reduction in manifold pressure will in turn cause an increase in the resistance of resistor 218 which will in turn cause the time delay to be longer. A rising voltage ahead of the gate turn-off triode 216 acts upon a time delay circuit 222 which includes a resistor 224 and capacitor 226 to cause this circuit to turn off a gate turn-off triode 228 which resets the entire circuit for the next cycle of the engine. Injection time and fuel quantity are adjusted to engine needs by manipulation of applied voltage, resistance and capacitance. In order to reset the gate turn-off triode 228, an engine driven reset switch 230 is closed which in turn grounds the reset circuit 232 which contains resistors 234 and 236, an inductor 238, and a capacitor 240. When the reset circuit is grounded, capacitor 240 discharges through resistor 236 and inductor 238 which in turn instantaneously grounds the anode 242 of the gate turn-off triode 228, allowing it to reset to the ON condition. When the reset switch 230 opens, the reset circuit is recharged through resistor 234 so as to be ready for its next cycle.

It will be perceived that the control circuitry provides for the synchronization of the operation of the solenoid controlled dual poppet valve with the speed at which the engine is operated. Moreover, adjustment can be made in the timing of the fuel injection and the quantity of the fuel which is injected during the injection time period by simple adjustments in the circuit.

In FIG. 7 of the drawings, a further modified form of injector valve useful in conjunction with the internal com-

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bustion engine of the invention is depicted. As here shown, the valve assembly includes a body 250 which is bored to provide a large chamber 252 in the upper portion thereof. The chamber 252 is closed by a suitable closure plate 254 which cooperates with a transverse partition 256 located in the chamber. Extending downwardly in the body 250 from one side of the chamber 252 is a relatively small counterbore 258 which accommodates the stem portion of a first valve member designated generally by reference numeral 260. A second relatively small counterbore 262 extends downwardly from the opposite side of the chamber 252 from the counterbore 258 and accommodates the stem of a second valve member designated generally by reference numeral 264.

At its upper end, the stem of the first valve member 260 carries a spring reaction plate 266 which bears against the lower end of a helically coiled valve return spring 268. In like manner, the upper end of the stem of the second valve member 264 carries a spring reaction plate 270 which bears against the lower end of a helically coiled valve return spring 272. The upper ends of the valve return springs 268 and 272 are seated in recesses 274 and 276, respectively, formed in the cover plate 254. Surrounding the upper portion of the stem of the first valve member 260 at a location immediately below the spring reaction plate 266 is an electrical solenoid 278. A second electrical solenoid 280 surrounds the upper portion of the valve stem of the second valve member 264.

A gaseous fuel inlet port 282 is formed in the side of the body 250 and communicates with a gas passageway 284 which intersects the lower end of the counterbore 258. At this location, a suitable valve seat 286 is formed which mates with the lower end of the valve member 260 to effect closure of the passageway 284 when the valve member is seated. A gas passageway 288 extends from below the seat 286 to a point of intersection with the counterbore 262, and at this location, a valve seat 290 is formed to mate with, and accommodate, the lower end of the second valve member 264. From a point below the valve seat 290, a gas passageway 292 extends to an internally threaded outlet port 294 which can be connected in any suitable way to an injection orifice through which gaseous fuel can be injected directly into the cylinder of the engine.

For the purpose of venting any gas which may leak past the seals around the valve members 260 and 264, a gas leakage passageway 296 is formed through the body 250 and can be vented through a suitable conduit threadedly connected to a leak port 298. Communication is established with the passageway 296 from the counterbore 262 by means of a passageway 300 formed through the body 250. For the purpose of purging this system in the manner hereinbefore described prior to commencement of operation with a combustible gaseous fuel, a purge gas passageway 302 is formed through the body 250 and communicates with a threaded purge port 304 formed in the side of the body.

The poppet valve assembly depicted in FIG. 7 is operated in a fashion substantially equivalent to that which has been described as characteristic of the other poppet valve embodiments illustrated herein. The dual poppet valve of FIG. 7, however, does not locate the paired valve members concentrically or coaxially. The solenoids 278 and 280 are, however, operated in the sequence previously described, so that the fast reaction of the valve which is necessary to achieve the desired injection sequence can be realized.

Although certain preferred embodiments of the invention have been herein described in order to illustrate the basic principles of the invention adequately for its practice, it is to be understood that various changes and innovations can be effected in the operating parameters described as typical of the process of the invention, as well as in the structures depicted and described as useful for carrying

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out this process. For example, other combustible fuels, such as gasoline, may be mixed with the hydrogen-air mixture in the engine cylinder to modify the effects of combustion to attain a specific engine performance or to reduce atmospheric contamination. Changes of this type which continue to rely upon the basic principles of the invention are deemed to be circumscribed by the spirit and scope of the invention except as the same may be necessarily limited by the appended claims or reasonable equivalents thereof.

What is claimed is:

1. A method of fueling an internal combustion engine which comprises:

passing an oxidant into each cylinder of the engine;  
injecting a gaseous combustible non-fossil fuel directly into each cylinder of the engine during the compression stroke commencing not earlier than 60° before top dead center;

forming a flame jet of ignited gaseous fuel extending into the cylinder from the point at which the fuel is injected into the cylinder;

continuously injecting gaseous fuel directly into each cylinder and concurrently effecting continuous combustion of the fuel-oxidant mixture in each cylinder until a time between top dead center and 90° from top dead center in the expansion stroke, at which time injection is terminated; and

exhausting the products of combustion from each cylinder.

2. A method of fueling an internal combustion engine which comprises:

passing an oxidant into each cylinder of the engine;  
injecting hydrogen gas into each cylinder of the engine during the compression stroke commencing not earlier than 60° before top dead center and continuously injecting hydrogen gas into each cylinder and concurrently effecting continuous combustion of the hydrogen gas-oxidant mixture in each cylinder until a time between top dead center and 90° from top dead center in the expansion stroke, at which time injection is terminated; and

exhausting the products of combustion from each cylinder.

3. The method defined in claim 2 and further characterized to include the step of igniting the hydrogen gas-oxidant mixture in each cylinder immediately following the commencement of hydrogen injection into each cylinder.

4. The method defined in claim 2 wherein said oxidant is air.

5. The method defined in claim 2 wherein injection of hydrogen gas is commenced not earlier than about 30° before top dead center.

6. The method defined in claim 2 wherein another combustible material is mixed with hydrogen gas and air in each cylinder.

7. The method defined in claim 2 wherein the rate and amount of hydrogen gas injection into each cylinder is correlated to engine speed and engine power.

8. The method defined in claim 3 wherein the injected hydrogen gas is initially ignited as it enters the cylinder to form a flame jet extending into the cylinder from the point of injection.

9. An internal combustion engine comprising:

a cylinder;  
a piston reciprocally mounted in said cylinder;

means for injecting a pressurized combustible gaseous non-fossil fuel directly into said cylinder at selected times during the stroke of the piston in said engine;  
timing means connected between said piston and said injecting means for operating the injecting means in response to piston movement to commence injection of said gaseous fuel directly into the cylinder during the approach of the piston toward the end of the compression stroke, and continuing said injection

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until the piston has undergone a portion of the expansion stroke; and

ignition means positioned in the cylinder adjacent the point of injection of said gaseous fuel therein for effecting continuous combustion of said gaseous fuel in said cylinder during said injection period.

10. An internal combustion engine as defined in claim 9 wherein said injecting means comprises a double poppet valve including

a pair of valve members; and  
a valve seat upon which said pair of valve members concurrently seat.

11. An internal combustion engine as defined in claim 9 wherein said injecting means comprises

a solenoid operated valve; and  
orifice means closable by said valve and positioned adjacent said ignition means.

12. An internal combustion engine as defined in claim 9 wherein said ignition means comprises a glow plug positioned in said cylinder.

13. An internal combustion engine as defined in claim 9 wherein said injecting means comprises a double poppet valve including:

a body having a bore therein;  
a pair of spaced counterbores extending from said bore;  
a first valve member in one of said counterbores;  
a second valve member in the other of said counterbores and spaced from said first valve member;  
a first electrical solenoid in said bore and positioned for retracting said first valve member in its respective counterbore toward said bore upon energization;  
a second electrical solenoid in said bore and spaced from said first electrical solenoid, said second solenoid being positioned for retracting said second valve member in its respective counterbore toward said bore upon energization;

first means in said bore for seating said first valve member when said first solenoid is de-energized;

second means in said bore for seating said second valve member when said second solenoid is de-energized; and

gaseous fuel passageway means through said body and closable at two different locations by seating of said first and second valve members.

14. An internal combustion engine as defined in claim 9 wherein said ignition means comprises a spark plug positioned in said cylinder.

15. An internal combustion engine as defined in claim 9 wherein said injecting means comprises:

a pair of poppet valves; and  
wherein said timing means comprises:  
an electrical control circuit comprising:  
at least two switching subcircuits; and  
at least two timing subcircuits, said timing subcircuits including means for controlling the switching function of said switching subcircuits to commence and terminate fuel flow through said valves to a cylinder of the engine in response to engine speed and power level.

16. An internal combustion engine as defined in claim 9 wherein said injection means comprises a double poppet valve assembly including:

a housing having a bore therein and having an orifice therethrough communicating with said bore;

a valve seat adjacent said orifice in said housing;

a first electrical coil in said bore;

a second electrical coil in said bore;

a first valve member reciprocally disposed in said bore for seating on said valve seat and having a portion extending into said first coil for response to the passage of electrical current through said first coil;

a second valve member reciprocally disposed in said bore for seating on said valve seat and having a portion extending into said second coil for response

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to the passage of electrical current through said second coil;  
 spring means acting individually on said first and second valve members to bias said valve members against said valve seat; and  
 fuel inlet passageway means in said housing for admitting gaseous fuel under pressure to said orifice when said first and second valve members are concurrently opened off said valve seat in response to passage of electrical current through said first and second electrical coils.

17. An internal combustion engine as defined in claim 16 and further characterized as including:  
 ignition means secured to said housing adjacent the opening of said orifice into said housing; and  
 means for supplying electrical energy to said ignition means extending through said housing from said ignition means to a point on said housing spaced from said ignition means.

18. An internal combustion engine as defined in claim 16 wherein said housing is elongated and said orifice opens into said housing at one end thereof;  
 and wherein said valve further includes means adjacent said one end of said housing for securing said housing to the cylinder of an internal combustion engine with said orifice communicating with the interior of the cylinder.

19. An internal combustion engine as defined in claim 18 wherein said bore extends axially in said elongated housing, and said housing further includes  
 a first counterbore communicating with said bore and concentrically surrounding portions of said first and second valve members; and  
 a second counterbore of lesser diameter than said first counterbore communicating with said orifice and said first counterbore and positioned therebetween

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and concentrically surrounding portions of said first and second valve members.

20. An internal combustion engine as defined in claim 19 and further characterized to include a retainer cap threaded into said bore;

and wherein said spring means comprises:

a first spring between said retainer cap and said first valve member; and

a second spring in said first counterbore and contacting said second valve member.

21. An internal combustion engine as defined in claim 20 wherein said second valve member includes

a sleeve concentrically surrounding a portion of said first valve member; and

a flange projecting radially outwardly from said sleeve and bearing against one end of said second spring.

## References Cited

## UNITED STATES PATENTS

1,275,481	8/1918	Seymour, Jr.	123—120
1,520,772	12/1924	Ricardo	123—119(E)
1,901,709	3/1933	Erren	123—39
1,905,627	4/1933	Holland	123—119X
2,183,674	12/1939	Erren	123—27(GAS)
2,365,330	12/1944	Carmichael	123—3X
2,376,479	5/1945	Fehling	123—1
2,431,857	12/1947	Fenney	123—32(G)
2,602,289	7/1952	Anxionnaz et al.	123—27(GAS)UX
2,937,634	5/1960	Kelseaux et al.	123—119(E)
3,471,274	10/1969	Quigley, Jr. et al.	123—1X

AL LAWRENCE SMITH, Primary Examiner

U.S. Cl. X.R.

123—27, 39, 119

# United States Patent [19]

Swain

[11] 3,799,124

[45] Mar. 26, 1974

[54] **HYDROGEN ENGINE AND METHOD OF FUELING SAME**

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[73] Assignee: **Pollution Free Power Corp.**, Miami, Fla.

[22] Filed: **May 5, 1972**

[21] Appl. No.: **250,809**

[52] U.S. Cl. .... **123/1 A, 123/52 M, 123/120, 123/DIG. 12**

[51] Int. Cl. ... **F02m 21/02, F02b 1/08, F02b 43/10**

[58] Field of Search ..... **123/1, 1 A, 39, 27 GE, 123/3, 119 E, 119, 32 ST, 127, 52 M, 139 AW, 120, DIG. 12**

[56]

## References Cited

### UNITED STATES PATENTS

3,703,886	11/1972	Witzky .....	123/32 ST X
2,183,674	12/1939	Erren .....	123/119 E UX
3,572,297	3/1971	Murray .....	123/1 A
2,365,330	12/1944	Carmichael .....	123/3 X
3,653,364	4/1972	Bogan .....	123/3
3,682,142	8/1972	Newkirk .....	123/3
3,710,770	1/1973	Newkirk et al. ....	123/120

3,648,668	3/1972	Pacheco .....	123/1 X
3,425,399	2/1969	Ward et al. ....	123/27 GE X
3,154,059	10/1964	Witzky et al. ....	123/32 ST UX

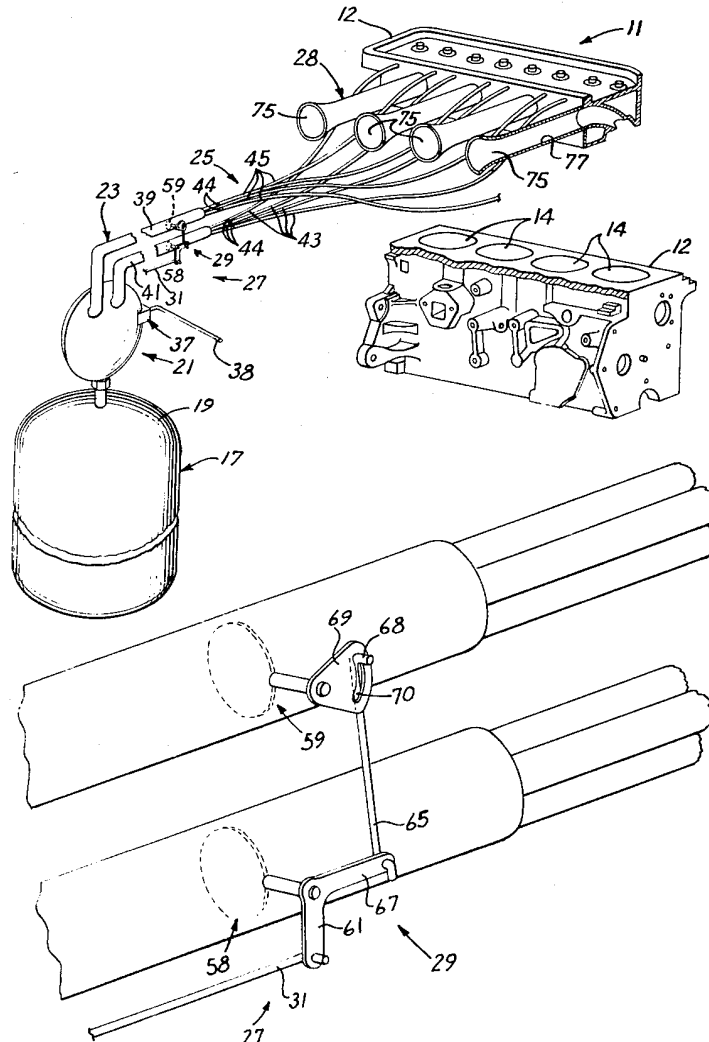
*Primary Examiner*—Al Lawrence Smith  
*Attorney, Agent, or Firm*—Fitch, Even, Tabin & Luedeka

[57]

## ABSTRACT

An internal combustion engine is fueled by hydrogen with the ratio of hydrogen to air within the combustion chamber or cylinder being varied to change the speed and power output of the engine and the flow of air to the engine is substantially unthrottled in contrast to the usual throttled flow of air and hydrocarbon fuel flowing from a carburetor to an engine. The preferred flow of hydrogen is substantially at ambient atmospheric pressure; and at light loads the hydrogen molecules may be concentrated within a portion of the chamber for combustion thereby burning a very lean charge of fuel. The engine and method of fueling provide higher thermal efficiencies, lower fuel consumptions and less pollutant emissions than similar engines fueled by a throttled flow of air-fuel mixtures, particularly hydrocarbon fuel-air mixtures.

14 Claims, 8 Drawing Figures



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FIG. 1

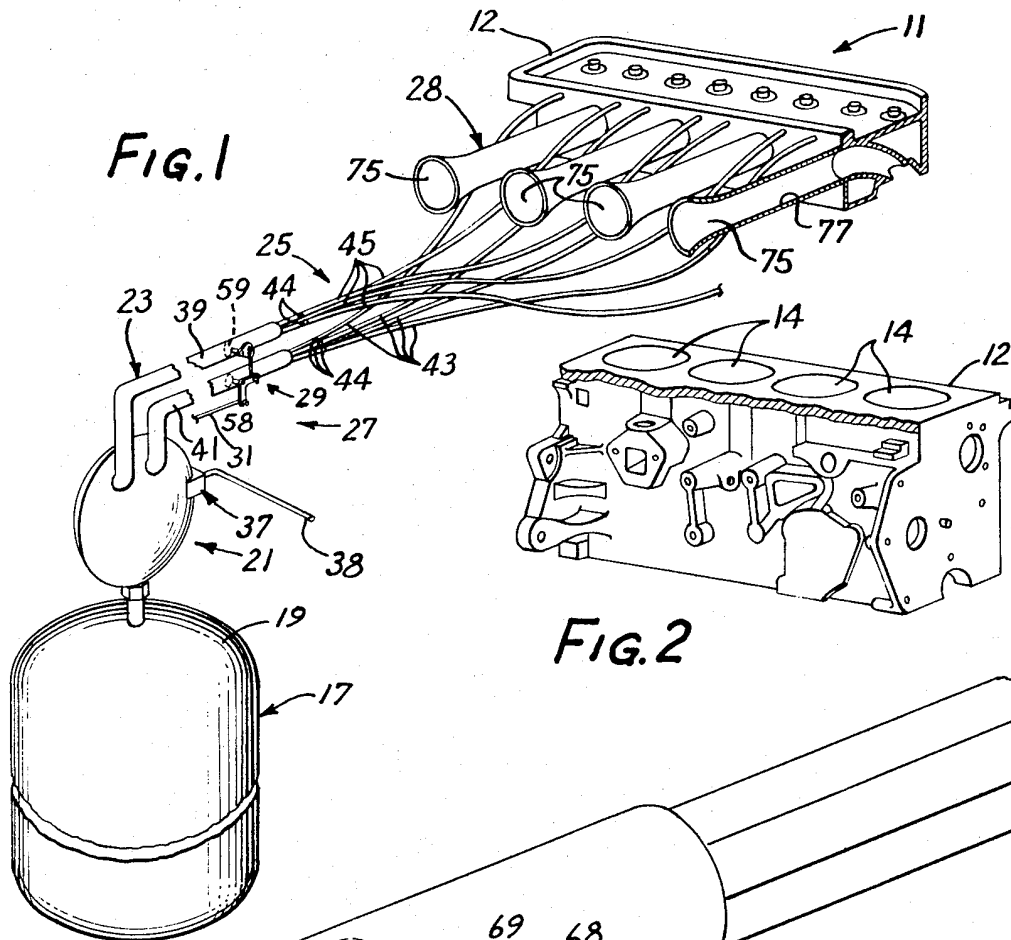


FIG. 2

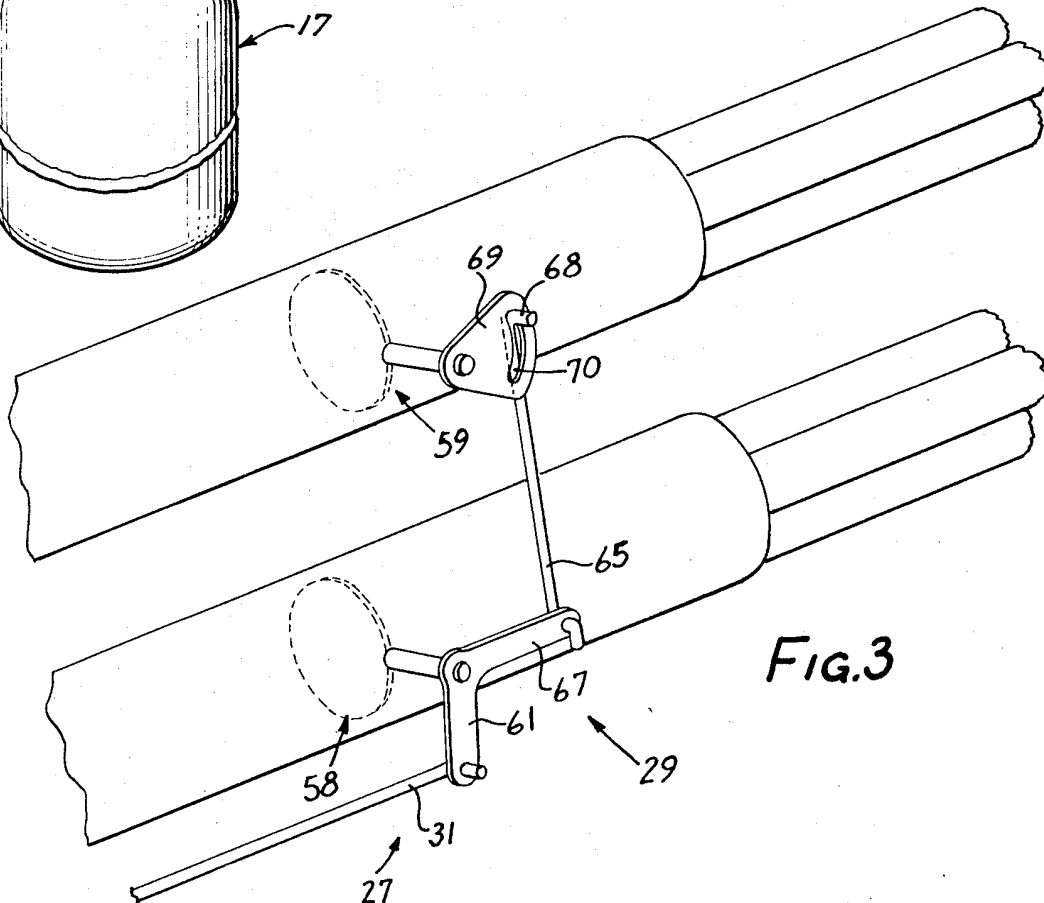
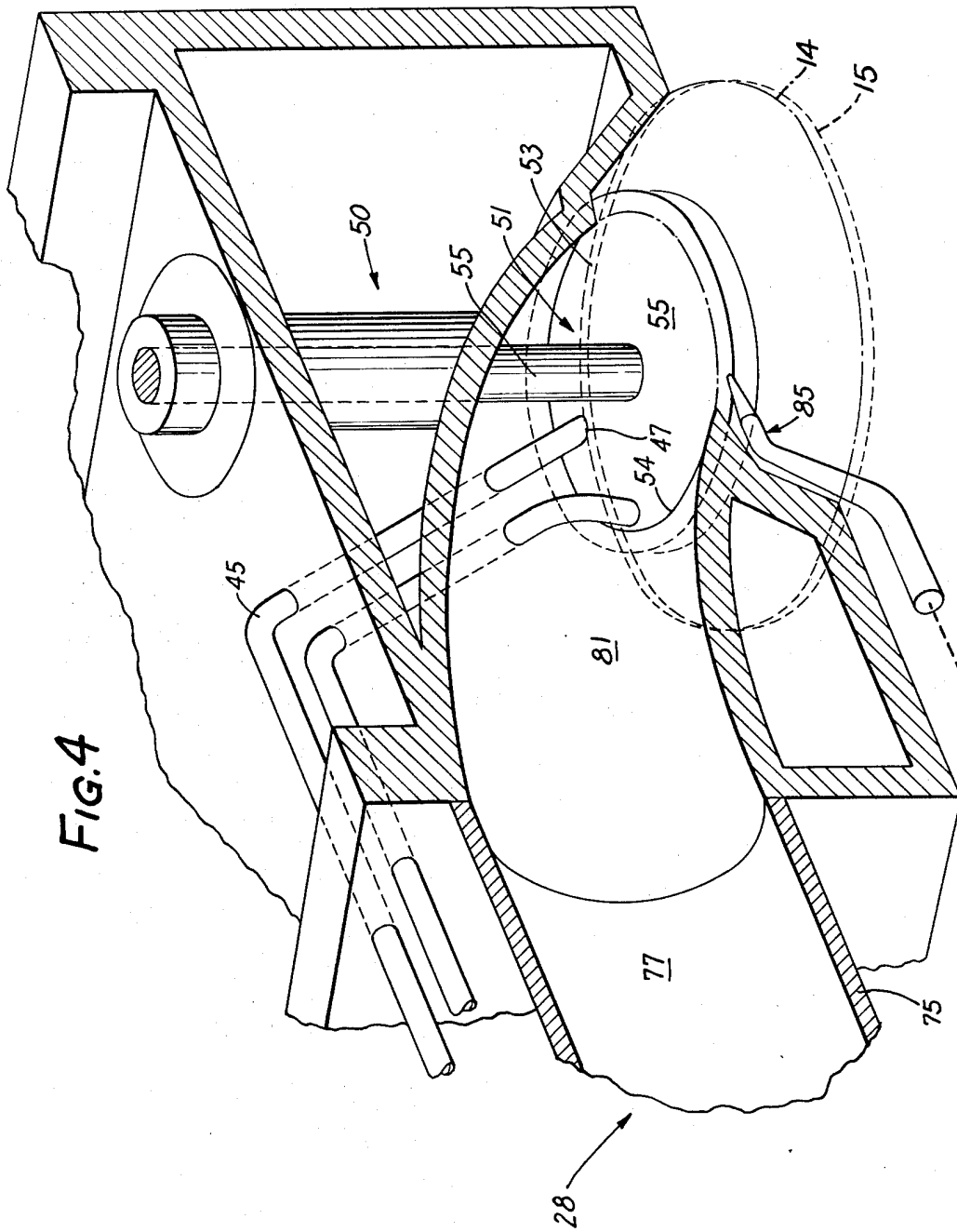


FIG. 3

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FIG. 6

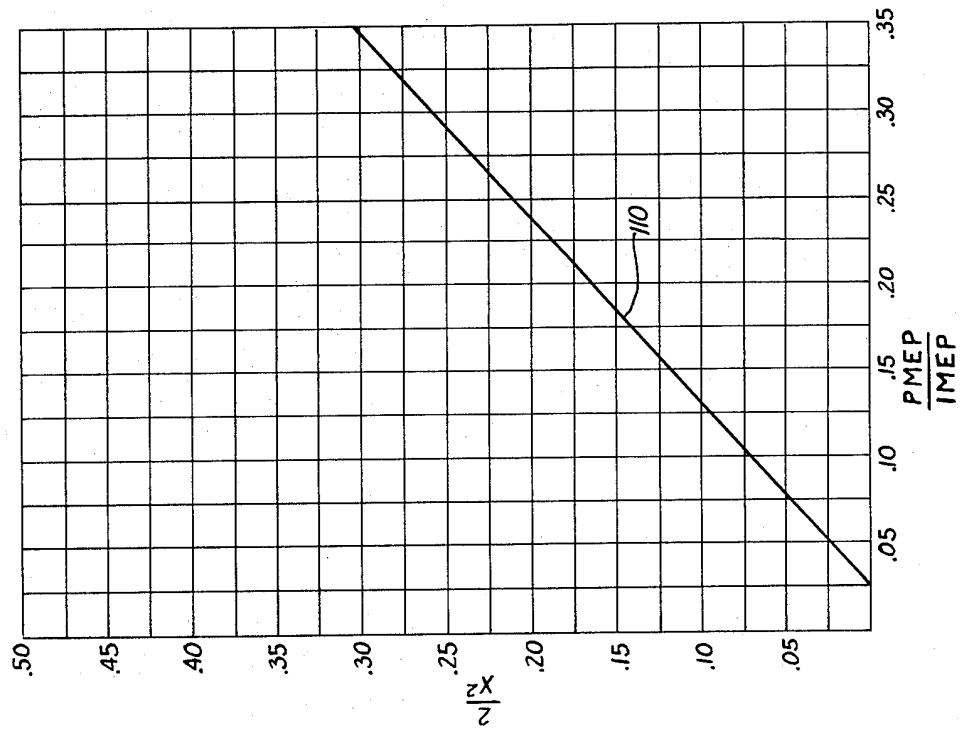
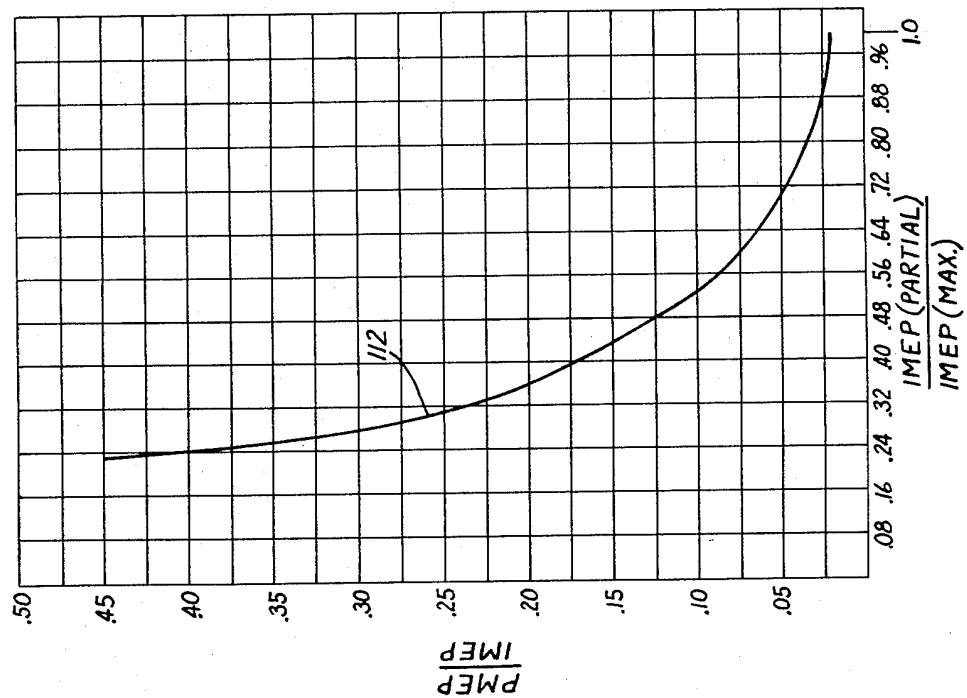


FIG. 5



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FIG. 8

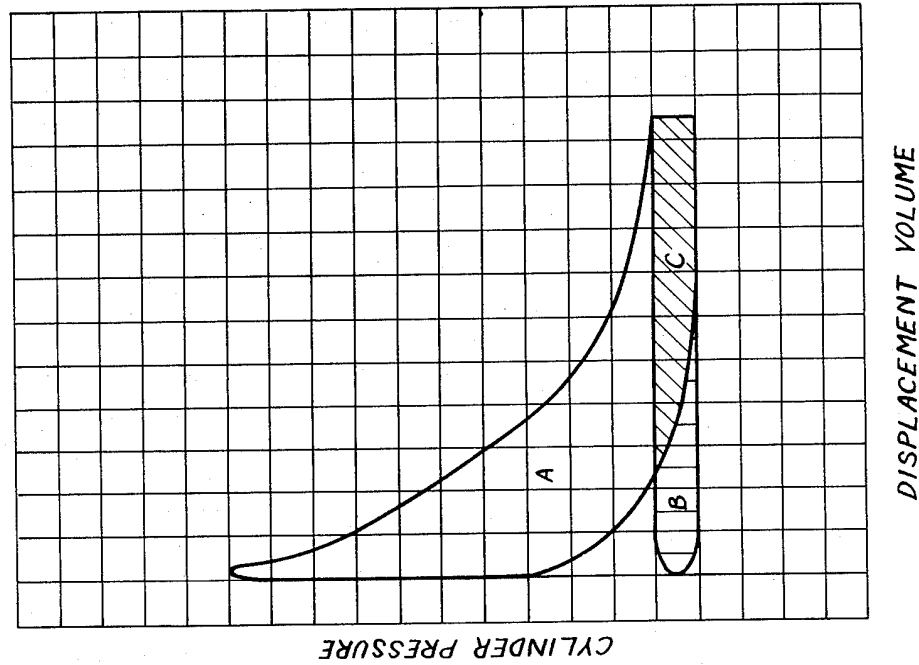
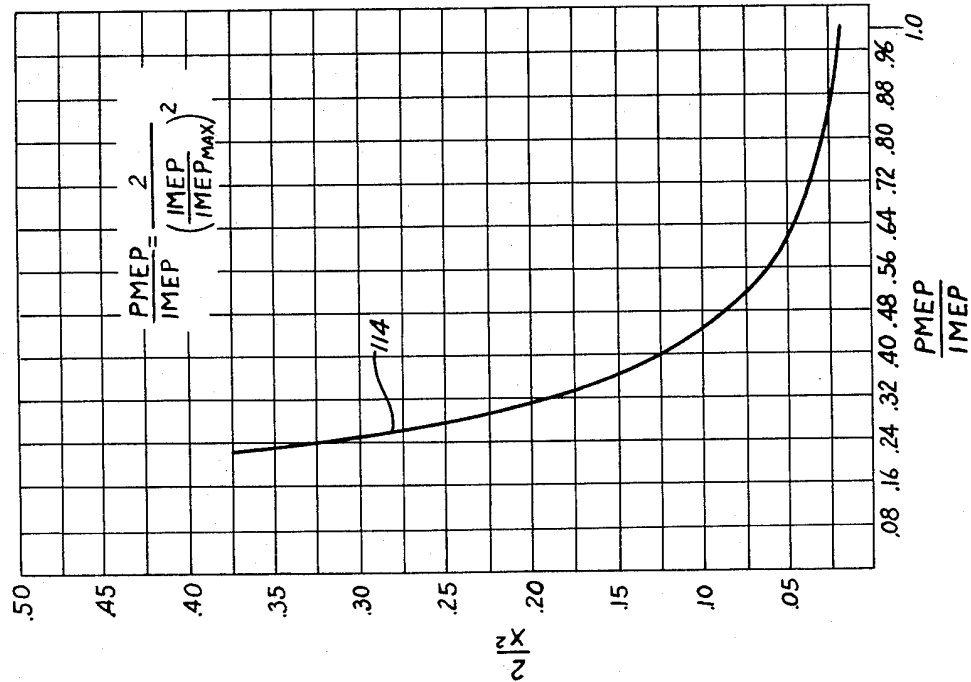


FIG. 7





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## HYDROGEN ENGINE AND METHOD OF FUELING SAME

This invention relates generally to internal combustion engines and more particularly to an internal combustion engine fueled by hydrogen and to a method of fueling an internal combustion engine with a fuel mixture of hydrogen and air.

The reduction of air pollutants from internal combustion engines has been the subject of considerable study and investigation. Virtually all of the internal combustion engines in present use in automobiles employ a hydrocarbon, fossil fuel which exhausts hydrocarbons, nitric oxides, carbon dioxide and carbon monoxide. Because of the extent of pollution in the atmosphere from current engines, the U.S. Government has set new emission standards for automotive vehicle engines which require a considerable reduction in pollutants over the next several years.

Gasoline, in addition to being a source of numerous and substantial quantities of air pollutants from the exhaust of an automotive engine, requires an extensive carburetor system and a complex manifold system to atomize the gasoline and distribute properly the atomized gasoline-air fuel mixture to each cylinder of the engine for various operating conditions including changes in demand for horsepower and speed without encountering preignition or backfiring problems. To control the speed and power, the gasoline-air fuel mixture is throttled extensively at the carburetor resulting in inefficiencies termed pumping losses herein. The tortuous manifold passages from the carburetor to the engine cylinders result in volumetric inefficiencies and these pumping losses coupled with the pumping losses due to throttling decrease the efficiencies of gasoline fueled automotive engines.

Although electric battery driven and various other engines have been suggested for powering automotive vehicles, the gasoline internal combustion engine has retained widespread usage in automobiles because of its ability to operate over a wide range of power demands and speeds, its quick response to demand for changes in power or in speed and because of its ability to be relatively inexpensively manufactured. Also, in addition to performance characteristics, the current gasoline engines have proven reliability coupled with a reasonable cost of operation. In short, current internal combustion engines used in automobiles will idle at light or no loads, will respond quickly to increases in demand for power, will accelerate a vehicle rapidly, will operate at light loads while cruising at high speeds and will run for substantially long periods of operation without having to stop for refueling. Regardless of what is done to develop substitutes for the internal combustion engine it is expected that at least 100 million more such engines will be built over the next 10 years, and the air we breath 10 years from now will depend to a large extent on how these engines are built and fueled.

The present invention is particularly directed to using the internal combustion engine because of its reliability and other proven qualities; and to adapting it to using hydrogen as a fuel for the twin purposes of reducing exhaust emissions therefrom as contrasted with exhaust emissions from gasoline fueled internal combustion engines and of providing a thermally more efficient engine. The hydrogen fueled engine and method dis-

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closed herein will be described in connection with vehicles but the engine and method of the invention may be used for purposes other than powering a vehicle.

In contrast to gasoline and other hydrocarbon fueled internal combustion engines hydrogen fueled engines will emit fewer pollutants with the substantial elimination of carbon monoxide and hydrocarbons; and with the efficiencies achieved with the new method of fueling the engine be more thermally efficient than a comparable gasoline fueled engine thereby resulting in fewer total polluting emissions per vehicle mile.

In contrast to a gasoline fueled internal combustion engine, water vapor, free N<sub>2</sub> and free O<sub>2</sub> are the principal constituents of the exhaust of the hydrogen fueled engine except, of course, when other fluids or gases are present as may result as a by-product of an on vehicle hydrogen generator or may be used for other purposes such as lowering nitric oxide emissions.

In accordance with a general object of the present invention, a new and improved hydrogen fueled internal combustion engine and method of fueling the same are provided.

These and other objects of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings in which:

FIG. 1 is a fragmentary, illustrative view of a fueling system and engine embodying the present invention;

FIG. 2 is a perspective view of an engine cylinder block used for the invention illustrated in FIG. 1;

FIG. 3 is an enlarged diagrammatic view of a control means used to regulate the flow of hydrogen to the engine shown in FIG. 1;

FIG. 4 is an enlarged view of an intake port to a combustion chamber and of separate passageways for air and hydrogen used in the engine shown in FIG. 1;

FIGS. 5, 6 and 7 are curves to illustrate engine performance; and

FIG. 8 illustrates an indicator card for an engine.

As shown in the drawings for purposes of illustration, the invention is embodied in an internal combustion engine 11 having a cylinder block 12 with a plurality of cylinders 14 therein. In a four-stroke cycle manner of operation pistons 15 (FIG. 4) in each cylinder 14 are reciprocated through an intake stroke, a compression stroke, a power stroke and an exhaust stroke. The engine 11 and its components, as best seen in FIGS. 1, 2 and 4 may be of conventional design in common use in automobiles except as otherwise described herein; but the engine is fueled with hydrogen and is modified in a novel manner to operate, preferably without the use of carburetor in this illustrated and preferred embodiment of the invention. The engine 11 may have its cylinders arranged in a conventional and standard V form rather than in the straight vertical in line form shown in FIG. 2. Manifestly, the number of the cylinders, the bore size thereof, the valving arrangement, the stroke of the pistons, connecting rod length or cam shaft design may be varied considerably from that described herein while employing the principles of the invention.

The use of hydrogen as a fuel for internal combustion engines has been investigated heretofore by other researchers. More specifically, early investigations by these researchers indicated that hydrogen-fuel air mixtures in internal combustion engines could produce suitable power, but these research efforts found that with hydrogen as a fuel there existed a tendency for the

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engine to knock and for the fuel to preignite unless low compression ratios and lean mixtures were used. Later experiments of others indicated that the knock and pre-ignition with a hydrogen-fuel mixture could be overcome at higher compression ratios provided that the combustion chambers were free of fluffy carbon deposits, the exhaust valve temperatures kept low, and low operating temperature spark plugs were used. However, the thermal efficiency results obtained by these other researchers when operating similar engines under similar operating conditions with gasoline or with hydrogen were not significantly different. While hydrogen-fueled, internal combustion engines have been investigated before; they have not been heretofore fueled and modified to achieve the efficiency as now obtained with the present invention.

In accordance with the preferred embodiment of the invention, very substantial improvements in thermal efficiency for an internal combustion engine are obtained with the use of a hydrogen fuel mixture rather than a hydrocarbon fuel such as gasoline and very improved emission results are obtained over the emissions obtained with gasoline fueled engines. The improved thermal efficiencies may be obtained by a fueling method which eliminates the carburetor and pumping losses associated therewith and by the use of very lean fuel-air ratios particularly when the engine is idling or at very light operating loads. In the preferred method of fueling, the ratio of hydrogen to air within the combustion chamber is varied to change the speed and power output of the engine in contrast to the usual throttling of the flow of the gasoline air mixture to change speed and power in the conventional gasoline engine. As will be explained in greater detail, advantage is taken of hydrogen's flame speed being faster than the flame speed of gasoline and hydrogen's wider range of ignition to allow the use of lean hydrogen to air ratios and to vary directly the flow of hydrogen into the combustion chambers to vary the engine's power and speed output. Also, as will be explained in greater detail, by admitting substantially unthrottled air flow into the cylinders 14 and by eliminating the tortuous manifolds and throttle plates of a carburetor, the pumping losses of the gasoline engine may be substantially reduced.

More specifically and in accordance with an important aspect of the invention, the engine 11 may be fueled at lighter loads in a manner to concentrate the lightweight molecules of hydrogen within a portion of each combustion chamber 14 to the extent that the ratio of hydrogen to air in each chamber may be actually less than that necessary for supporting combustion considering the volume of the combustion chamber as a whole. For example, it has been possible to convert a standard gasoline engine to use hydrogen gas and to swirl the gas in the center of the combustion chamber to achieve a very lean below 4.1 percent (by volume) of hydrogen to air in the fuel mixture being burnt; whereas, if the hydrogen were homogeneously dispersed within the entire volume of the combustion chamber, the percentage of hydrogen to air would have to be about at least 4.1 percent. Thus, at no or low loads, it is possible to stratify or concentrate the lightweight molecules of hydrogen to burn a very lean charge which results in a high thermal efficiency for the engine, lower fuel consumptions, and less pollutant emissions.

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In the preferred fueling system, hydrogen is stored in a supply means 17, in this instance in the form of a metal cylinder 19 holding a compressed gaseous form of hydrogen at a pressure substantially higher than ambient atmospheric pressure. Hydrogen from the supply means 17 flows through a pressure regulator means 21 in which the pressure of the hydrogen is reduced substantially from the pressure at which the hydrogen is stored in the supply tank 19. In this instance, the pressure regulator means 21 reduces the pressure of hydrogen to the ambient atmosphere or slightly thereabove for flow through a conduit means 23 to an intake conduit means 25 leading to the cylinders 14.

In accordance with another important aspect of the invention, the engine 11 may be fueled with an induction technique without the use of a carburetor or without an expensive fuel injector system for spraying fuel into a combustion chamber while the air is compressed therein. As will be explained in greater detail, hydrogen at substantially atmospheric pressure may be inducted into the cylinders 14 during the intake stroke of the pistons 15 therein; and an unthrottled flow of air may be provided through an air inlet means 28 into the cylinders 14 during the intake strokes. By allowing unthrottled flow of air into the cylinders 14, the substantially low subatmospheric pressures experienced with carburetor fueled and throttled gasoline engines may be substantially eliminated. This relatively high vacuum on the combustion side of the pistons facilitates oil flow past the piston rings and the mixture of oil with the fuel thereby adding to the polluting emissions of a gasoline engine, particularly as the engine becomes older and the piston rings become worn.

With a free flow of air into the cylinders 14 during the intake stroke, the leanness or richness of the fuel mixture is controlled by a control means 27 for metering the flow of hydrogen to the cylinders 14 in response to movement of an actuator 31 which may be operated by an accelerator pedal (not shown) as in an automotive vehicle. The illustrated control means 27 is in the form of a valve means 29 which meters the flow of hydrogen to the cylinder intake conduit means 25. As will be explained, when the engine is idling the valve means permits a predetermined, low flow rate of hydrogen through the conduit means 25; whereas with increased demand as by an operation of the actuator 31, the valve means will open further and permits a larger flow rate of hydrogen through the intake conduit means 25 and into the cylinders to increase the percentage of fuel in the cylinders 14. As the air intake means 28 is open and unthrottled, the percent of air in the cylinders varies inversely and proportionally to the percentage of hydrogen fuel being admitted into the cylinders. An additional advantage of this method is that the intake manifold does not contain explosive mixtures of hydrogen and oxidant; this minimizes the hazards associated with backfiring.

Referring now in greater detail to the illustrated hydrogen engine 11 and to the preferred manner of fueling the same, the engine 11 is modified to advantageously capitalize on the attributes of hydrogen, particularly as contrasted with gasoline as a fuel for an internal combustion engine.

More specifically, hydrogen has a flame speed faster than gasoline and has a good flame speed over a range of fuel air ratios larger than gasoline-air fuel ratios. As used herein the term hydrogen refers to a gas or gas

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mixture which is largely dependent on the formation of oxygen-hydrogen bonds for the production at available energy to do work. This gas then may contain percentages of other gases which are either the by-products of an on board hydrogen generation source, constituents added to reduce nitrogen oxides emissions or increase octane number. One of the shortcomings of gasoline is that it will not support a sufficiently fast flame speed for use in internal combustion engines over very low gasoline-air ratios as will hydrogen. Additionally, hydrogen has a faster flame speed and burns over a wider range of fuel-air ratios, e.g., about 4.1 percent to 74 percent hydrogen to air by volume, than hydrocarbon fuels such as methane, ethane, ethylene and acetylene. This flame speed characteristic of hydrogen at the lean side of air-fuel ratios is advantageously used herein, e.g., for a 1971 Toyota 1600 an 8 percent hydrogen-air fuel ratio is used at cruising speed for an automotive vehicle and below 4.1 percent hydrogen to air fuel ratio may be used for idling. With the engine 11 illustrated, the maximum fuel ratio of hydrogen-air is about 31.3 percent hydrogen for maximum power.

Although the hydrogen is illustrated as being stored in a compressed gaseous state in a cylinder 19, the induction system of the present invention is particularly adaptable for use with hydrogen generated at low or near ambient atmospheric pressure. Hence, this invention may be used to eliminate the drawbacks of a need for high pressure fuel tanks and fuel supply stations therefor. For instance, hydrogen may be stored at low pressure by a hydride, such as magnesium-nickel or magnesium-copper hydride, from which it is thought that hydrogen may be recovered economically, safely and in sufficient quantities to provide a long-range fuel supply comparable to the range achieved with present day gasoline storage tanks on automobile engines. Of course, liquid hydrogen could be stored and evaporated to supply the hydrogen introduced into the combustion chambers. In addition, a number of chemical reactions release hydrogen (oxidation of ferrous metals, aluminum, calcium hydride, etc.) which may provide a suitable source for fueling a hydrogen powered vehicle. In addition, hydrogen can be generated on the vehicle by the reaction of water and a hydrocarbon fuel such as gasoline, kerosene, etc., the resulting fuel being a mixture of mainly hydrogen gas and carbon dioxide. The gaseous by-products from the hydrogen gas generating process may also be passed through the engine before being exhausted.

The operator of the hydrogen engine 11 may be provided with means for providing responsiveness of the hydrogen engine to demands for increased speed or power by providing the control means 27 with a flow rate increase means 37 which, in this instance, increases the flow rate by increasing the pressure of gaseous hydrogen in the conduit means 23 and consequently an increase in flow rate of hydrogen past the valve means 29 and into the cylinder 14. For instance, the flow rate means 37 may be operated in response to a manual movement of the vehicle operator such as through an actuator 38 in the form of a control rod connected to the pressure regulating means 21 to reset the level of its output pressure to a higher level whereby an output of hydrogen gas at a higher pressure than the normal pressure is obtained across the pressure regulating means 21. The increase in hydrogen pressure is transmitted almost instantaneously, i.e., at

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about the speed of sound through the conduit means 23 which is very high in hydrogen gas, to the valve means 29 and if the latter is open, an increased pressure through the intake conduit means 25 results in an increased flow rate of hydrogen to the cylinders 14 than would be realized had the pressure remained substantially constant. Thus, by the combination of the metering of the valve opening and the pressure of the gas flowing through the intake conduit means 25 the hydrogen engine can be made particularly responsive to demands for increased speed or load.

The illustrated conduit 23 is in the form of a primary hydrogen flow conduit or pipe 41 and a secondary hydrogen flow conduit or pipe 39 each which extends from the outlet of the pressure regulating means 21 to the control valve means 29. The fuel supply means 17 may be at a remote location as is the usual gasoline supply tank. In this instance, hydrogen flows through the pipe 41 during heavy power or speed demands and hydrogen flows through the pipe 39 only at light loads. The illustrated intake conduit means 25 has an assembly of primary induction tubes 43 connected in fluid communication with the primary pipe 41 and extending to each cylinder 14. Likewise, an assembly of secondary induction tubes 45 are each connected to one of the combustion chambers 14 to admit hydrogen to each chamber with proper operation of the control valve means 27. The secondary induction tubes 45 are, as best seen in FIG. 2, provided with outlets 47 which discharge generally at the center of each cylinder 14 and in a manner to swirl the hydrogen to form the stratified concentrated charge at the center of the chamber. On the other hand, for the heavier power and speed demands, the primary induction tubes 43 deliver to the sides of the combustion chambers a richer mixture of hydrogen in excess of the 4.1 percent hydrogen to air. The flow and distribution of hydrogen to each of the cylinders may be regulated by a flow control means to compensate for different path lengths and curves in the intake tubes. The flow control means may take various forms such as an adjustment screw 44 projecting into each tube 43 and 45 for turning to open or restrict gas flow therethrough.

The particular shape, number and operation of an intake valve means 51 may be varied considerably for a number of considerations such as efficiencies of flow, ease of manufacturing, etc. For purposes of illustration only, the intake valve means 50 comprises a single valve means 50 comprising a single valve member 53 for each cylinder 14 movable by a suitable actuator 55 between a lowered open position in which hydrogen and air may flow through an intake port 54 into the cylinder 14 and an upper closed position in which a back or upper surface 55 of the valve member 53 abuts and covers the outlets of the hydrogen intake tubes 43 and 45. With closure of the valve member 53, the intake port is also closed to the air intake means 28.

When using two separate sets of intake tubes 43 and 45 and only a single intake valve member 53 for each cylinder 14, the valve means 29 controls which set of the intake tubes 43 and 45 will be open to hydrogen flow therethrough. The valve means 29 accomplishes this flow control by having a primary valve 58 and a secondary valve 59 each controlling flow through its respective primary and secondary pipes 39 and 41 to the respective manifold sets of intake tubes 43 and 45. preferably, the valves 58 and 59 are operated by a com-

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mon operating means 69 which, in turn, is operated by the actuator 31 which is connected to the vehicle accelerator. With operation at loads and speeds substantially above idling loads and cruise, the valve 58 opens and meters the flow rate of hydrogen through the intake induction tubes 43 to discharge hydrogen in the cylinders 14 near the cylinder walls thereof, and if necessary destroys the induction swirl. With pulling of the actuator 31 in the direction of the arrow, it pulls on an attached bell crank 61 to turn it in a clockwise direction, as viewed in FIG. 1, to operate its internal valve member (not shown) for example, a butterfly valve member to open the same to the extent of turning of the bell crank. A link 65 is attached to an arm 67 of the bell crank and the link has a lost motion connection with a valve operator cam 69 for the valve 59. More particularly, the lost motion connection comprises a hook 68 on the link inserted into a curved slot 70 in the operator cam 69. The hook 68 will travel freely in the curved slot until abutting the end of the slot after which continued turning of the bell crank in the same direction turns the operator cam 69 to reposition the valve member between open and closed positions. The actuator 31 will, as by spring pressure, with release of the accelerator pedal, return the bell crank 61 to the illustrated position blocking hydrogen flow through the intake tubes 43 while the other valve member is in an open position allowing hydrogen to flow through the intake induction pipes 45 to discharge at the outlets 47 adjacent the center of the combustion chambers.

It is to be understood that the intake conduit means 23 may comprise only a single conduit or pipe rather than the illustrated plurality of pipes 39 and 41. Also, the intake means 25 may comprise only a single set of intake tubes, one for each cylinder rather than two tubes 43 and 45 illustrated for each cylinder. In such event, the valve means 29 may comprise only a single valve. It will be appreciated that the intake conduit means 23, control means 27, and air intake means may take various other forms to provide the method of fueling with hydrogen herein described and claimed.

Additionally, the concentration of the lightweight hydrogen molecules may be obtained in various manners by the use of various means, e.g., directional ports, flow diverting vanes, fins above the intake valve, or spiral or snail shaped ports, partially recessed valve seats, quench areas producing swirls or shrouded valves. Various other means may be used to direct the flow to provide the concentrated charge for combustion when the overall hydrogen is below 4.1 percent of the total combustion chamber volume. Moreover, it is possible to provide a premixing chamber in which the hydrogen and air would be mixed prior to introduction into the combustion chambers.

For the purpose of providing the substantially unthrottled flow of air and to avoid the pumping losses and inefficiencies in fluid flow found with tortuous manifolds and carburetor of gasoline engines, it is preferred that the air be conveyed through the air intake means 28 which is in the form of substantially straight flow pipes 75 having a substantially straight and smooth flow directing wall 77 extending from an air inlet end 79 to an air discharge end 81 located adjacent or at the intake valve 53. Thus, with air being taken in on the intake stroke and through a wide cross-sectional bore of generally non-tortuous configuration, the pressure experienced within each cylinder during an intake stroke

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should be near the atmospheric ambient pressure rather than substantially below ambient atmospheric pressure heretofore experienced with gasoline engines during the intake strokes thereof. These high pressure differentials in gasoline engines cause oil to migrate past the piston rings into the combustion chambers; and they also cause large pumping losses and inefficiencies. It has been found that the pumping losses can be reduced with the present hydrogen induction system and that the brake thermal efficiency may be increased by as much as 48 percent. The separate air intake pipes 75 may be connected to a common air filter (not shown) or have individual filters to trap dirt and other foreign matter from flowing with the air into the cylinder.

A combustion ignition means such as a Champion N60R spark plug is provided to ignite the hydrogen-air fuel mixture. The ignition occurs during the compression stroke or the first 50° of the power stroke and time of ignition is dependent on the air-fuel ratio, load, speed, etc. Due to reasonably low minimum spark ignition energy requirements stock ignition systems may be used. To avoid the fluffy carbon deposits and the preignition problems associated therewith in the hydrogen engine 11, special lubricating oils may be used such as, for example, a paraffin based oil or a silicone or synthetic based lubricant. Also, it is preferable to use a low-operating temperature spark plug such as Champion N60R for the hydrogen engine 11 to avoid preignition problems heretofore found when using the usual standard temperature gasoline engine spark plugs.

While the engine 11 described is a four-cycle engine, the hydrogen engine 11 may be a two-cycle engine having its intake, compression, power and exhaust processes achieved within two strokes of the engine. The engine will be described in connection with the use of free air from the ambient atmosphere to supply the oxidant; but the engine may be operated with pure oxygen from a storage tank in other environments, e.g., in a submarine environment, and the exhaust of the engine will be substantially water.

Principles of the present invention have been tested on a vehicle originally powered with a gasoline internal combustion engine but converted to use hydrogen as a fuel. This engine was successfully operated with hydrogen with only one intake conduit for hydrogen per cylinder.

When the hydrogen engine 11 is built as original equipment for vehicles a number of other changes may be made advantageously. For instance, because the flame speed of hydrogen is faster than the flame speed of gasoline, the bore to stroke ratio for the engine may be changed and larger cylinder bores may be used to reduce the amount of friction losses now being experienced with gasoline internal combustion engines. Also, because of the faster flame speed for hydrogen, hydrogen engines embodying the invention may be provided with a reduced fuel burning time loss as contrasted with present gasoline internal combustion engines for automobiles. In lieu of using sodium filled exhaust valves to reduce the temperature thereof, two smaller exhaust valves may be used rather than one large exhaust valve. Also, with larger intake valve capacity and larger exhaust valve capacity, the hydrogen engine may be operated at a higher efficiency. Also, the control means 27 could be in the form of fluid amplifiers to control and direct hydrogen to the proper cylinder or in the form

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of rotary valves, or spool valves as part of the valve stem-valve guide assembly, or orifice at valve seat 85.

As the hydrogen fueled engine 11 has no gasoline atomization problems and may eliminate therefrom complex manifolding passageways, water may be more easily injected into the hydrogen-air fuel mixture than into a gasoline-air fuel mixture. The water injection will maintain a lower temperature in the combustion chamber thereby reducing the nitric oxides in the exhaust gas of the hydrogen engine. The gases exiting the exhaust valve and port may be recirculated into the combustion chamber for the same purpose.

Power measurements of an engine may be made by means of indicator cards which illustrate pressure-volume measurements as best seen in FIG. 8. Pressure-volume measurements from such indicator cards may be used, as will be explained, to distinguish in quantitative terms a "substantially unthrottled" system of a hydrogen engine in accordance with this invention from a throttled system used in a conventional gasoline or fossil fueled engine. Herein, a substantially unthrottled engine may be quantitatively defined as being when  $PMEP/IMEP < 2/X2$  where  $PMEP$  is Pumping Mean Effective Pressure; where  $IMEP$  is Indicated Mean Effective Pressure and where

$$X = (IMEP \text{ (part load)})/IMEP \text{ (full load)}.$$

For a given engine, the IMEP is calculated from a pressure-volume indicator card such as the indicator card, curve 100 FIG. 8. IMEP is equal to the sum of area A and area C. The  $PMEP$  is calculated as the sum of area B and area C shown in FIG. 8. The area A is indicative of the pressure-volume measurement for the compression and power strokes. The areas B and C are indicative of the pressure-volume measurement for the intake and exhaust strokes. Of course, with various operating conditions and parameters for various engines, the respective areas will vary in size and shape.

In a "substantially throttled" engine as defined herein the ratio of Pumping Mean Effective Pressure to Indicated Mean Effective Pressure will be less than  $2/X2$ , and beneath the curve 110, shown in FIG. 6. The valves used to plot the graph shown in FIG. 6 are as follows:

TABLE I

$\frac{IMEP^1}{IMEP^2}$	1.00	0.615	0.46	0.307	0.231
$\frac{PMEP}{IMEP}$	0.02	0.07	0.13	0.25	0.45
$\frac{2}{X2}$	0.02	0.0528	0.0944	0.212	0.375

<sup>1</sup> Partial. <sup>2</sup> Max.

FIG. 6 illustrates in quantitative form that the hydrogen engine will have volumes below the curve 110 whereas the throttled engines will have values above the line 110.

A curve 112 graphed in FIG. 5 illustrates the ratio of Pumping Mean Effective Pressure to Indicated Mean Effective Pressure as plotted against the ratio of Indicated Mean Effective Pressure at part load to Indicated Mean Effective Pressure for a full load for the values given in Table I.

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A curve 114 in FIG. 7 also plots the data disclosed in Table I with the values for  $2/X2$  along the ordinate and for  $IMEP \text{ (partial)}/IMEP \text{ (max)}$  along the abscissa.

From the foregoing, it will be seen that the present invention provides a hydrogen engine operable to provide a substantial reduction in contaminants in its exhaust in contrast to present day commercial automobile gasoline engines. By use of the hydrogen induction fueling method, increased thermal efficiency as compared to a gasoline engine for a vehicle may be achieved. Also, the present invention may be employed by modifying gasoline internal combustion engines to retain the proven reliability, wide power and speed range characteristics thereof yet with better efficiency and with better exhaust emissions.

The internal combustion engine 11 illustrated in the drawings having reciprocating pistons in cylindrical chambers 14 is only illustrative of the present invention as the present invention also encompasses internal combustion engines of the rotary kind, e.g., the Wankel engine, in which a rotary piston or rotor rather than a reciprocating piston is used as the member driven by the burning of the fuel in a non-cylindrically shaped chamber. In a rotary internal combustion engine, hydrogen may be induced to flow into the rotary piston chamber through the intake conduit means 25 with the natural motion of the rotary piston acting as a valving mechanism for controlling the flow of hydrogen, air and exhaust gas into or from the chamber 14. Thus, it will be understood that the terms "piston", "chamber" and "member driven by an increase in fluid pressure with burning of the fuel" are generic to such elements in either a rotary or reciprocating kind of internal combustion engine.

While a preferred embodiment has been shown and described, it will be understood that there is no intent to limit the invention by such disclosure but, rather, it is intended to cover all modifications and alternate constructions falling within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A method of fueling an internal combustion engine with a hydrogen-air fuel mixture for ignition by a spark igniting means in a chamber with a member therein driven by an increase in fluid pressure with burning of the fuel, said method comprising the steps of controlling the flow rate of hydrogen flowing to said chamber, inducing the flow of hydrogen into said chamber during an air intake movement of said member in said engine, conveying a substantially unthrottled flow of air and combining the same with said hydrogen during the intake movement of said member to form an ignitable homogeneous fuel mixture for burning said homogeneous mixture in said chamber with operation of said spark-igniting means, during compression and expansion strokes burning said homogeneous mixture, and adjusting the flow rate of hydrogen with changes in demand for speed or power output from said engine while said flow of air remains substantially unthrottled.

2. A method in accordance with claim 1 including the step of inducing the flow of said hydrogen into said chamber at substantially ambient atmospheric pressure through paths of flow separated from paths for air flow to said chamber.

3. A method in accordance with claim 1 including the further step of raising the pressure of hydrogen to pro-

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vide an increase flow rate for said hydrogen in response to an increased demand for power of speed.

4. A method in accordance with claim 1 including the further step of controlling the flow of hydrogen to each chamber by opening and closing valves formed from the motion of the valve train for said engine.

5. A method in accordance with claim 1 including the step of adding water, water vapor, or carbon dioxide to said hydrogen-fuel mixture to lower the temperature of the burning and thereby reduce the nitric oxide emissions from the engine exhaust.

6. A method in accordance with claim 1 including the further step of generating a hydrogen containing gas and passing any gaseous by-products from said hydrogen generating step including carbon dioxide gas through said hydrogen burning engine.

7. An internal combustion engine for burning a hydrogen air fuel mixture, said engine comprising in combination: a plurality of combustion chambers for receiving a homogeneous mixture of air and hydrogen therein, a piston movable in each of said combustion chambers during an intake of hydrogen-air, a compression of the hydrogen and air, a burning of the hydrogen-air fuel mixture, and exhaust of the resultant products of burning, means for burning said air fuel mixture in said combustion chamber during said compression and expansion strokes, an intake conduit means extending to each of said combustion chambers and for conducting the flow of said fuel mixture by induction on said intake strokes of said pistons, a supply means containing hydrogen connected to said intake conduit means to supply hydrogen to said intake conduit means, and control means for selectively regulating the flow of hydrogen from said supply means to said intake conduit means to vary the speed and power output of said engine, said varying of said hydrogen flow by said control means causing an inversely proportional change in the percentage of air in said fuel mixture and resulting in a substantially constant volume charge to said cylinders.

8. An internal combustion engine in accordance with claim 7 in which said hydrogen supply means stores hydrogen gas at a pressure above a predetermined level, and in which said control means includes a pressure regulator for reducing the pressure of hydrogen from said supply means to said intake conduit means.

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9. An internal combustion engine in accordance with claim 8 in which said pressure regulating means provides hydrogen to said intake conduit means at a first pressure substantially equal to ambient atmospheric pressure and in which said control means further comprises means for providing an increase in pressure for the hydrogen gas flowing through said intake conduit means to provide a fast response for a demand for an increase in power or speed for said engine.

10. An internal combustion engine in accordance with claim 7 in which said intake conduit means comprises hydrogen intake tubes projecting to said combustion chambers and air intake pipes extending to said combustion chambers, said hydrogen intake tubes and said air intake pipes being separate and discrete from each other.

11. An internal combustion engine in accordance with claim 10 in which said air intake pipes each have a substantially smooth continuous wall defining a passageway extending from adjacent said cylinders to an open end thereby alleviating inefficiencies due to flow about sharp corners.

12. An internal combustion engine in accordance with claim 7 in which said intake conduit means comprises a first set of intake tubes for conveying hydrogen for light power and speed demands to said combustion chambers and a second set of intake tubes for conveying hydrogen to said combustion chambers for heavier power and speed demands.

13. An internal combustion engine in accordance with claim 7 in which said intake conduit means comprises a set of intake tubes for conveying hydrogen and distribution adjusting means are provided for regulating the flow and distribution of hydrogen through the respective ones of said tubes.

14. An internal combustion engine in accordance with claim 7 including a valve train means operatively associated with said combustion chambers, valves in said valve train associated with each of said combustion chambers to move between an open position allowing flow of hydrogen gas into its associated combustion chamber and a closed position preventing flow of hydrogen gas into its associated combustion chamber, and means in said valve train for opening and closing said valves in timed relationship to each other.

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# United States Patent [19]

## Underwood

[11] 3,862,624

[45] Jan. 28, 1975

### [54] OXYGEN-HYDROGEN FUEL USE FOR COMBUSTION ENGINES

[76] Inventor: **Patrick Lee Underwood**, 13285 Dyer St., Sylmar, Calif. 91342

[22] Filed: **Apr. 6, 1973**

[21] Appl. No.: **348,503**

#### Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 79,475, Oct. 10, 1970.

[52] U.S. Cl. 123/119 A, 123/DIG. 12, 123/119 B, 123/120, 60/39

[51] Int. Cl. F02m 25/06

[58] Field of Search 123/DIG. 12, 119 A, 119 E, 123/119 B, 120; 60/39-46

#### References Cited

##### UNITED STATES PATENTS

883,240	3/1908	Sabathe.....	123/119 E
1,275,481	8/1918	Seymour, Jr. ....	123/119 E
1,750,919	3/1930	Becker.....	123/119 A
2,478,682	8/1949	Blackwood.....	123/119 A
2,742,885	4/1956	Thwaites et al.....	123/119 A
3,101,592	8/1963	Robertson et al. ....	123/DIG. 12
3,362,386	1/1968	McMahon.....	123/119 B
3,362,883	1/1968	Wright.....	123/DIG. 12
3,559,402	2/1971	Stone et al.....	60/39.46 X
3,608,529	9/1971	Smith et al.....	123/DIG. 12

3,672,341 6/1972 Smith et al..... 123/DIG. 12

#### FOREIGN PATENTS OR APPLICATIONS

736,486 5/1943 Germany..... 123/119 E  
831,429 9/1938 France..... 123/119 E

Primary Examiner—Wendell E. Burns

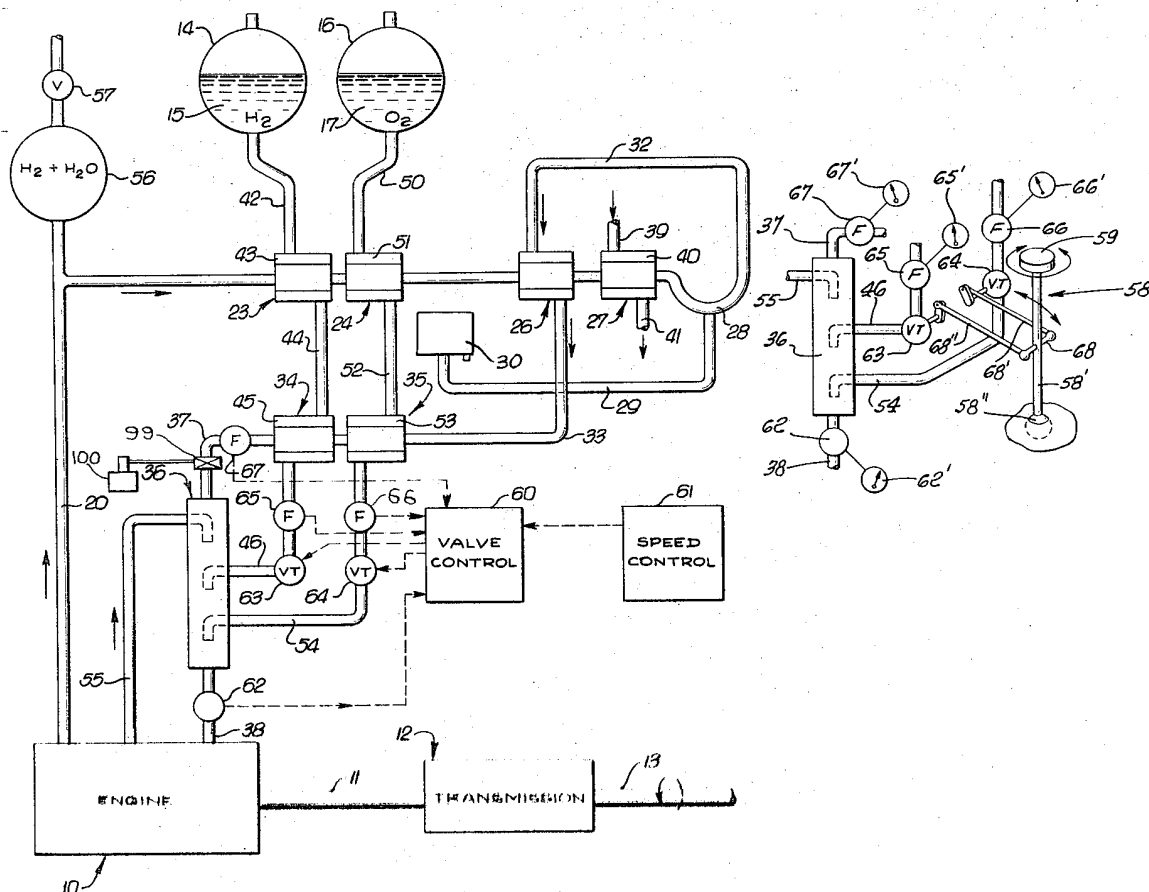
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#### ABSTRACT

A combustion engine which uses in combination oxygen and an excess of hydrogen as fuel has a substantially closed exhaust system which recirculates the gaseous part of the exhaust through the engine and expels only water. Hot engine exhaust is cooled by heat exchange contact with supplies of oxygen and hydrogen and the oxygen and hydrogen are simultaneously warmed by the exchange of heat. A trap separates water from the excess hydrogen, and the excess hydrogen and blowby exhaust from the engine are mixed with fresh supplies of oxygen and hydrogen before the mixture is injected into the engine for combustion.

Throttle valves are adjusted to vary the quantity of oxygen and hydrogen for speed control and at the same time maintain a proper proportioning of the gases at whatever quantity flow may be established for a selected speed.

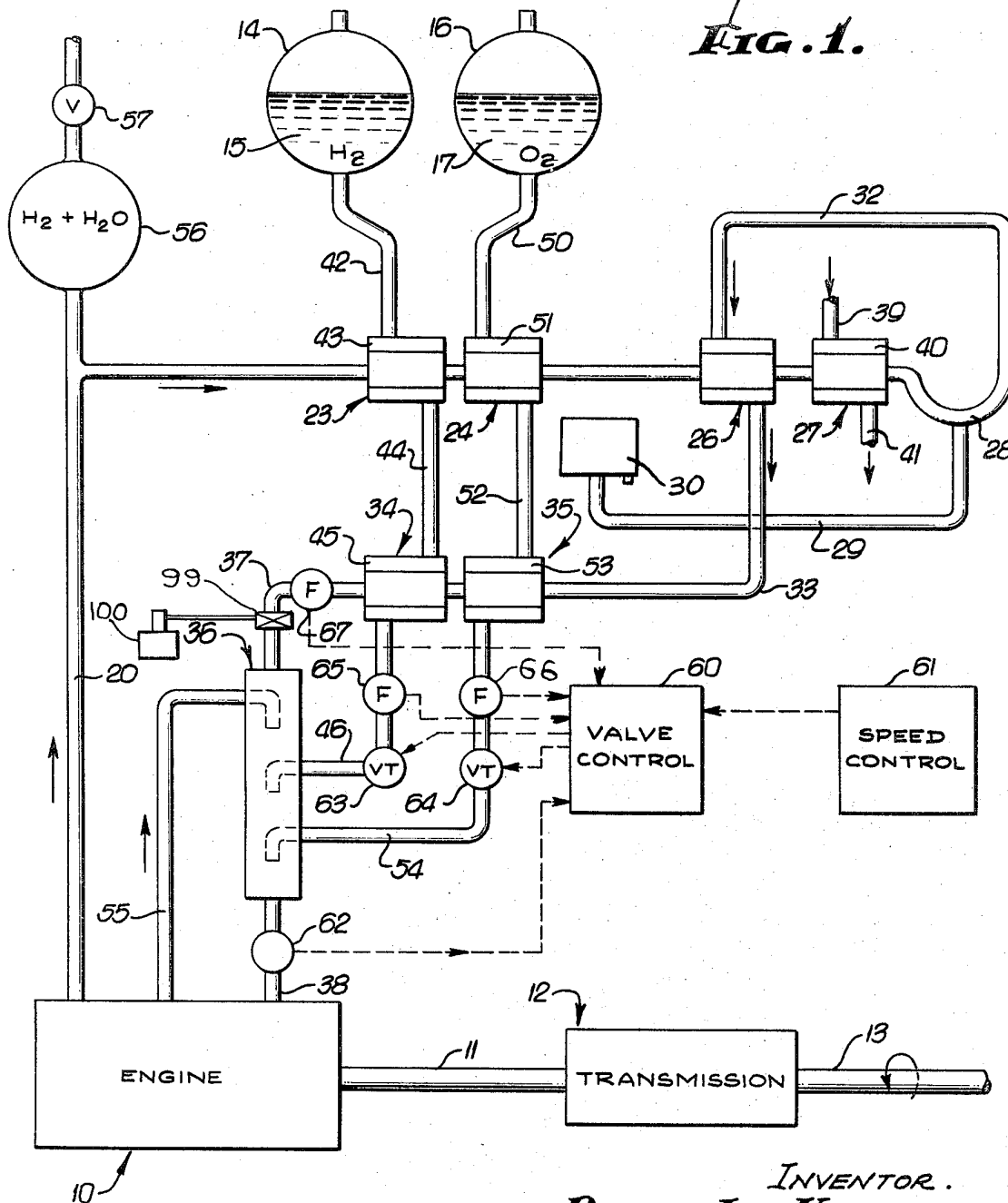
10 Claims, 5 Drawing Figures



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**FIG. 1.**

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FIG. 2.

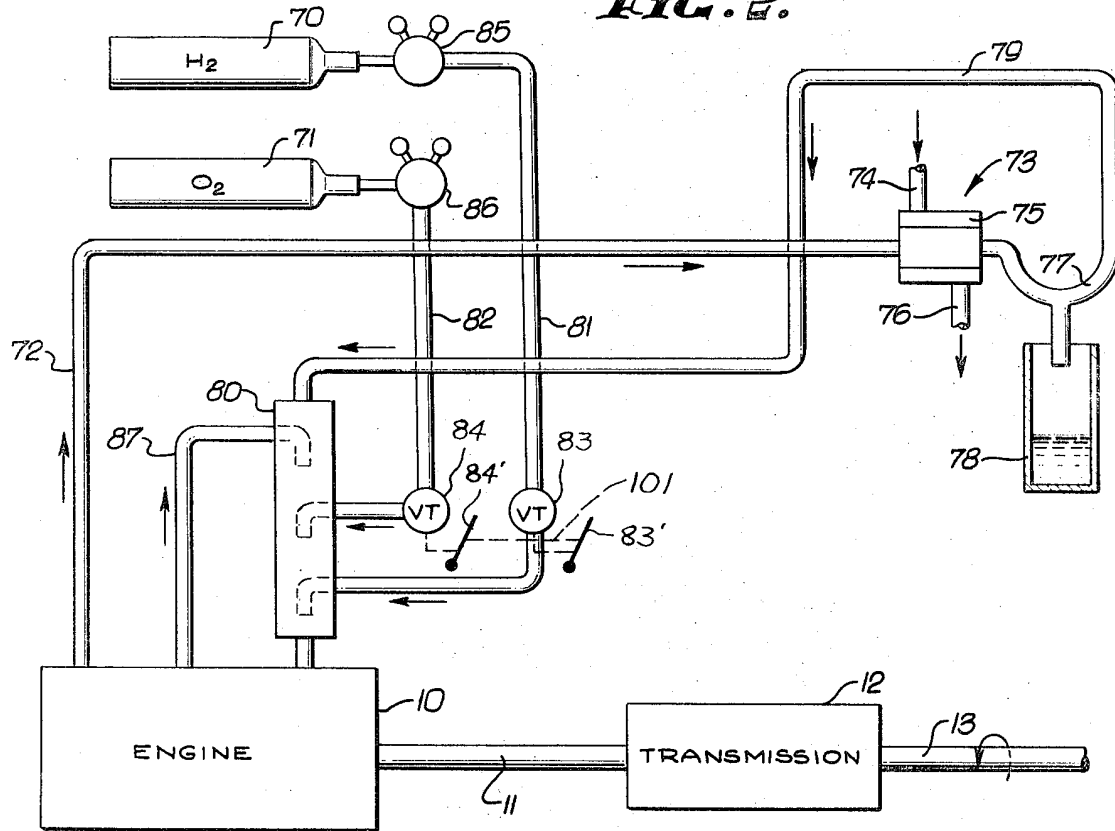
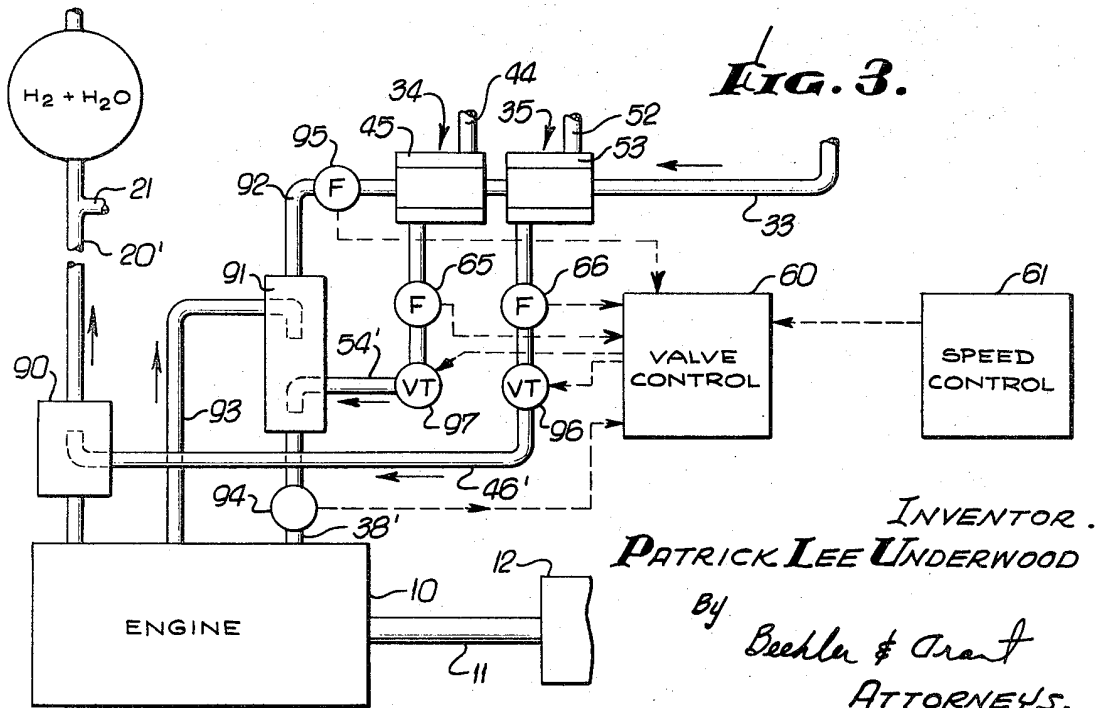


FIG. 3.



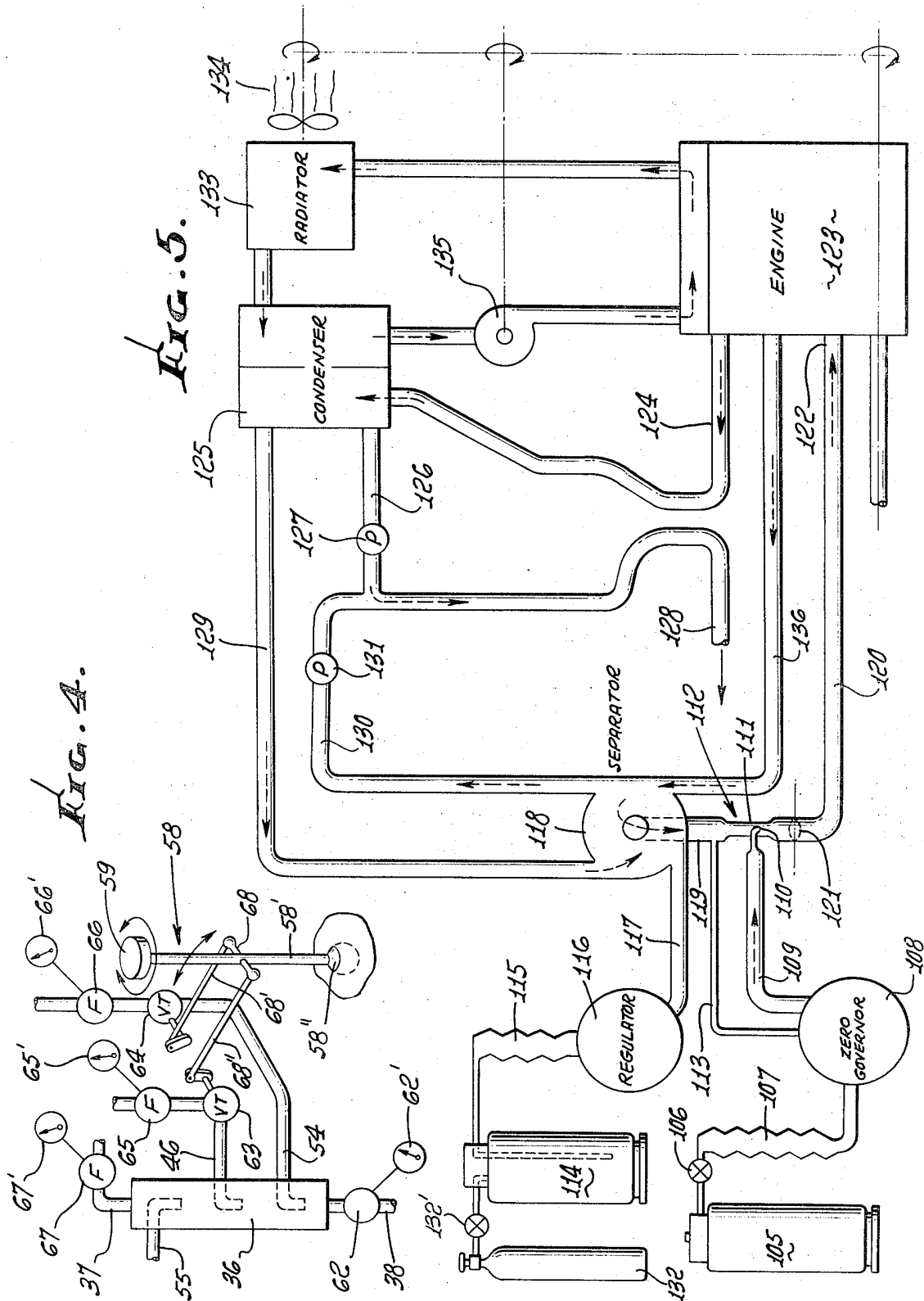
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## OXYGEN-HYDROGEN FUEL USE FOR COMBUSTION ENGINES

This is a continuation-in-part of the copending application, Ser. No. 79,475, filed Oct. 10, 1970. su

The object of the invention is to eliminate completely all pollutants from the system exhaust of a conventional internal combustion engine without the necessity of modifying the basic engine design.

Exhaust pollutants from internal combustion engines fueled by hydrocarbons and using air as an oxidizer consist of fuels not fully oxidized, oxides of nitrogen, carbon monoxide and various chemicals formed in the cylinder by reaction of the fuel additives with the oxygen and nitrogen of the air within the high pressure, high temperature and electric arc presence in the environment of the normal otto cycle engine common to current automotive propulsion systems. Although carbon dioxide is produced by humans and animals, internal combustion engines fueled by hydrocarbons produce carbon dioxide at a sufficiently great rate to be considered a pollutant. Although some water is also produced by engines fueled by hydrocarbons water is not generally considered a pollutant.

In the invention here disclosed, hydrogen and oxygen are used as fuel so that water is the only product of combustion and thus is not a pollutant by any definition. In this example, removal of water is accomplished by taking the engine exhaust, consisting of water vapor, hydrogen and miscellaneous inert gases and partially or fully oxidized elements, and passing the mixture through a condenser next to a separator to remove the liquid water and then returning the remaining gaseous portion of the mixture to the intake manifold of the engine. The separated water may be collected in a reservoir, or may be exhausted from the system directly in the liquid state.

The miscellaneous returned gases are mixed with a quantity of hydrogen sufficient to regulate the engine speed. The blowby gases from the engine crankcase, consisting mostly of hydrogen but having some oxygen, water vapor, lubricating oil vapor and miscellaneous other substances, and sufficient oxygen to oxidize an amount of the hydrogen provided for engine speed control are added to the mixture. This mixture is then introduced into the engine intake manifold for normal combustion and subsequent exhausting from the engine to complete the recirculation cycle. Miscellaneous gases referred to in this foregoing description can be an inert gaseous component, hydrogen only, oxides of nitrogen, carbon dioxide, or other combination of gases suitable to retard the flame speed and to provide an expansion medium when the engine is not operating at full throttle.

Among the objects of the invention is to provide a new and improved fuel cycle for an internal combustion engine which will substantially eliminate exhaust of substances commonly identified as atmosphere pollutants.

Still another object of the invention is to provide a new and improved fuel system for an internal combustion engine in which the only exhausted component is water.

Still another object of the invention is to provide a new and improved fuel system for an internal combustion engine which improves the quietness of operation of the engine, which eliminates the need for muffler

and carburetor and which, when fueled with hydrogen, avoids the formation of engine oil acid.

Additionally included among the objects of the invention is to provide a new and improved fuel system for a combustion engine wherein, by use of hydrogen and oxygen in liquid state as a source of energy, makes possible employment of the system as a cooling expedient to take the place of the conventional air-conditioning device, and provide a cooling air conditioner for such vehicle as may be operated by use of the system.

With these and other objects in view, the invention consists in the construction, arrangement, and combination of the various parts of the device, whereby the objects contemplated are attained, as hereinafter set forth, pointed out in the appended claims and illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a schematic representation of one form of the fuel system which contemplates employment of hydrogen and oxygen in liquid state.

FIG. 2 is a schematic representation of a second form of the invention which makes use of oxygen and hydrogen as fuel in a compressed gaseous state.

FIG. 3 is a schematic representation of a somewhat modified form of the invention illustrated in FIG. 1.

FIG. 4 is a manual control for operation of all forms of the invention.

FIG. 5 is another form of the invention showing a different means for controlling engine speed.

In one embodiment of the invention chosen for the purpose of illustration there is shown a substantially conventional combustion engine indicated generally by the reference character 10 which, acting through a shaft 11 and transmission 12, is adapted to operate a drive shaft 13.

Fuel for the engine is contained in a reservoir 14 adapted to contain a quantity 15 of liquid hydrogen and a reservoir 16 adapted to contain a quantity of liquid oxygen 17.

Inasmuch as recirculation of the engine exhaust is an important phase of the system attention is initially directed to an engine exhaust line 20 and its extension 21 which is served by a series of heat exchangers 23, 24, 26, and 27 at the end of which is a water separating device in the form of a trap 28. Inasmuch as the fuel for the engine is a mixture of oxygen and hydrogen the principle ingredient of the exhaust is water which, in view of the series of heat exchangers, has been converted to liquid and which, by operation of the trap 28, is separated out passing through an exhaust liquid line 29 and deposited into a reservoir 30.

Since the system is designed and adapted to operate with a surplus of a selected gaseous ingredient which is part of the engine exhaust mixture, a surplus gas return 32 leading from the trap 28 passes through the outer jacket of the heat exchanger 26 on its way to a pipe 33 and ultimately back to the engine 10.

More specifically the pipe 33 is directed through two additional heat exchangers 34 and 35 and then enters a mixer 36 by way of a pipe 37. An intake manifold 38 receives fuel gas from a pipe 38' at the outlet of the mixer and passes it to the engine 10.

The heat exchanger 27, serving as a condenser and previously identified as being located in the extension 21 of the exhaust line, may be a substantially conventional heat exchanger such for example as a radiator of

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the type commonly used on automotive vehicles, capable of circulating cooling water through an inlet 39 and then around a jacket 40 to an outlet 41.

Since liquid hydrogen and liquid oxygen respectively in the reservoirs 14 and 16 tend to emerge in cold condition from the reservoirs, it is desirable to warm these fuels before they reach the mixer 36 and are injected into the engine. To accomplish this, a pipe 42 from the oxygen reservoir 14 communicates with a jacket 43 of the heat exchanger 23 and is warmed by the heat of the engine exhaust. A pipe 44 from the jacket 43 communicates with a jacket 45 of the heat exchanger 34 where the hydrogen is warmed additionally by heat which remains present in the surplus gas returning through pipe 33, action of the heat exchangers 23 and 34 thereby serving to convert liquid hydrogen into gaseous hydrogen before it passes through a supply pipe 46 to the mixer 36.

Similarly, a pipe 50 from the oxygen reservoir 16 passes liquid oxygen to a jacket 51 of the heat exchanger 24 from which it flows through a pipe 52, converted into gaseous form, to a jacket 53 of the heat exchanger 35. From the jacket 34 oxygen passes through a supply pipe 54 on its way to the mixer 36 and ultimately to the engine 10.

To complete the circuit there is provided a blowby exhaust line 55 which accepts exhaust from the crankcase of the engine and passes it to the mixer 36. It follows therefore that the mixer 36 receives gaseous components from several different sources, namely the blowby exhaust, the surplus gas return, and the fresh fuel supplies of oxygen and hydrogen wherein all are mixed before being returned to the inlet side of the combustion engine.

In the engine exhaust line 20 is an accumulator 56 equipped with a relief valve 57 to prevent overpressuring of the system.

Because of inherent differences in flow rates of hydrogen and oxygen upon changes in demand, it is advantageous to make use of an automatic valve control 60 responsive jointly to a speed control 61 and a pressure gauge 62 at the intake manifold in controlling throttle valves 63 and 64 respectively in the hydrogen supply pipe 46 and oxygen supply pipe 54, thereby to control the quantity of oxygen fuel and make up hydrogen being introduced to the mixer 36 and, in consequence, to control the speed of the engine. The speed control may, if desired, be entirely manual.

Flow meters 63 and 64 respectively in the same hydrogen supply line 46 and oxygen supply line 54 are connected respectively to the automatic valve control 60. A flow meter 67 in the pipe 37 returning surplus gas to the mixer 36 is similarly connected.

The flow meters 65, 66, and 67, of conventional construction, provide the valve control with information indicating the rate of flow in the respective pipes. Related information is provided by the pressure gauge 62 to the flow meter giving pressure at the intake manifold. By a conventional integrating system, not part of the present invention, the valve control 60, when activated by the speed control 61 at the volition of the operator, mechanically operates the flow controls 63 and 64 in either an opening direction for speed up of the system or in a closing direction for lessening speed. Equivalent operation can be achieved by manual manipulation of the flow controls directly by the speed control.

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As operation of the circuit progresses the engine exhaust is partially cooled by action of the heat exchangers 23, 24, and 26 before reaching the heat exchanger 27 and the trap 28, the trap 28 being designed to prevent escape of the surplus gas from the system. On those occasions where the surplus gas is hydrogen the trap will separate hydrogen into the water which is the product of the combination of two parts hydrogen and one part oxygen made use of as the explosive mixture to operate the engine.

A substantial excess of hydrogen is made use of which may be ninety-two parts by volume over and above the quantity of hydrogen necessary for combustion. When the surplus gas, which in the present example is surplus hydrogen, passes through the heat exchangers 34 and 35, the surplus gas will be brought to substantially the temperature of the fuel and oxidizer which in the present example is hydrogen and oxygen, before all, by their separate supply pipes, are passed to the mixer 36.

The purpose of the flow meters 65, 66, and 67 is to provide information to the valve control 60 to maintain proper net volumetric supply ratio of two parts of hydrogen to one part of oxygen for proper combustion. During the acceleration mode, excess hydrogen and water vapor are stored in the accumulator 56 until constant speed is reached, or the deceleration mode has started. The relief valve 57 will vent excess pressures developed in the accumulator by system operation as has been previously noted.

As an example of manual control of the quantity of oxygen and hydrogen to the manifold to change engine speed reference is made to FIG. 4. As there shown a battery of indicators reveal visually the flow conditions at various locations at any given instant. An indicator 67' is connected to the flow meter 67, an indicator 65' to the flow meter 65 and an indicator 66' to the flow meter 66. Where further flow information can be made use of an indicator 62' may be provided connected to the pressure gauge 62.

A speed control throttle lever 58 has an arm 58' on a universal mounting 50''. A cross bar 68 has one end attached to a link 68' for manipulation of the throttle valve 64 for oxygen and the other end attached to a link 68'' for manipulation of the throttle valve 63 for hydrogen. A handle 59 on the arm 58' may be thrown forwardly or rearwardly to open or close both throttle valves simultaneously thereby to alter the speed of the engine. At the same time the handle 59 may be rotated to vary the relative openings or closings of the throttle valves.

Because of the different molecular weights of oxygen and hydrogen, flow rates vary with respect to each other depending on demand for quantity of the respective gases. Hence for higher speeds, by way of example, a greater quantity of both gases will be needed but at the proportionate quantities of freshly supplied gases. The proportion must remain at a ratio of two parts oxygen to one part hydrogen as delivered to the intake manifold 38. Because of the fact that when subject to greater demand the flow rates vary, the amount of opening of the control throttle 63 relative to the amount of opening in the control throttle 64 needs to be changed slightly.

As a guide to the operator in adjusting the manual settings the indicators 66', 65' and 67' respectively constantly supply a visible indication of flow in the ox-

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ygen and hydrogen in the supply lines 52 and 44 respectively, and also flow in the surplus gas return line 37. As a safety feature the indicator 62' shows the flow condition at the manifold at a point where all gaseous components have been combined. This is a warning as to how rapidly or slowly changes in quantity flow, and accordingly speed control, should be made.

Although an additional surplus gas such as argon or one of the other suggested gases may be introduced initially into the system the selected surplus gas or surplus gas of any selected kind to the system may be added later.

Exhaust circuit illustrated in FIG. 2 a somewhat different arrangement is illustrated consisting of fewer components but in which the fuel hydrogen and oxidizer oxygen are stored respectively in pressure cylinders 70 and 71 in the compressed gas state. An engine exhaust line 72 conducts gaseous engine exhaust to a heat exchanger 73, operating on substantially conventional principles to cool the exhaust gases by a cooling liquid flowing from an inlet 74 to a jacket 75, and, thence, outwardly through an outlet 76. The cooling effect is made sufficient such that be the cooled exhaust gases reach a trap also the resulting water is separated out and dumped into a receiver 78 and the remaining surplus gas, passes through a surplus gas return line 79 for ultimate delivery to the combustion engine.

A mixer 80 receives the surplus gas from the surplus gas return line 79 and also receives hydrogen from the hydrogen supply line 81 and oxidizer namely oxygen from an oxygen supply line 82. The flow of hydrogen is controlled by means of a manual throttle valve 83 manipulated by a lever 83', oxygen being controlled by means of a manual throttle valve 84 manipulated by a lever 84', before being passed to the mixer 80. A hydrogen pressure regulator 85 controls hydrogen pressure to the supply line 81 and an oxygen pressure regulator 86 controls oxygen pressure to the supply line 82.

To complete the recirculation cycle a blowby exhaust line 87 takes exhaust from the engine crankcase and passes it to the mixer 80.

Oxygen and hydrogen in this form of the circuit being initially supplied as gases serve to minimize need for the numerous heat exchangers described in connection with the FIG. 1 circuit and the engine speed can therefore be more directly controlled by the throttle valves 83 and 84 linked in a conventional manner by linkage 101 which, in the event that the engine is an automotive engine, would be the driver of the vehicle.

In still another modified form of the circuit as illustrated in FIG. 3 hydrogen from the hydrogen supply pipe 46' is conducted to an injector 90 in an engine exhaust line 20' in a manner such that hydrogen gas as fuel first flows from the engine exhaust line 20' to the extension 21 and thence through all of the heat exchangers 23, 24, 26, and 27 before passing into the engine intake manifold 38' from a modified mixer 91 by way of a pipe 92.

As previously described in connection with the forms of invention of both FIG. 1 and 2, blowby exhaust passes through a blowby exhaust line 93 to the modified mixer 91 where it mixes with the fuel gas, the oxidizer, and the surplus gas before being passed through a flow meter 94 to the intake manifold 38' and thence to the engine 10.

The flow meter 94 in the form of FIG. 3 is adapted to be controlled by the flow control 60, similar to the

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flow control 60 in FIG. 1, or by the manual control of FIG. 4.

In the form of device of FIG. 3 oxygen, after passing through the customary heat exchangers shown in connection with FIG. 1, is fed to the modified mixer 91 from an oxygen supply pipe 54'.

A flow meter 95 in the pipe 92 serves a purpose similar to that described for the flow meter 67 in FIG. 1. Throttle valves 96 and 97 respectively for hydrogen and oxygen, working through a valve control like the valve control 60 of FIG. 1 and speed control 61 of FIG. 1 serve to control the quantities of hydrogen and oxygen respectively fed to the engine and thereby control the speed.

Although an excess of hydrogen has been used in the description of the circuit and its operation, it should be understood that the surplus gas may be some other gaseous ingredient such as one of the inert gases like argon or a mixture of such gaseous elements. Under some circumstances air may be used as the surplus gas, or some other gas which will not take part in the oxygen-hydrogen combustion. To make it possible to inject surplus gas of any kind, there may be provided in the pipe 37 a conventional three-way valve 99 supplied by a container 100 which contains the desired additional surplus gas.

Proportions of the surplus gas may vary, typical examples productive of acceptable results being as follows:

Example 1:	Oxygen 20%
	Hydrogen 80%
Example 2:	Oxygen 4%
	Hydrogen 96%
Example 3:	Oxygen 8%
	Hydrogen 92%

The invention in the form illustrated in FIG. 5 exemplifies an alternative expedient for introducing oxygen under control to the system at a location such that the speed control of a standard internal combustion engine can be governed by a simple butterfly valve.

The system embodies a container 105 of liquid oxygen held preferably under a pressure of 80 pounds per square inch. Oxygen from the container passes to a conventional regulator 106 where the pressure is lowered to a pressure of 10 pounds per square inch at 70° Fahrenheit. From here the oxygen passes through a vaporizer 107 and then to a governor 108. From the governor oxygen passes through a supply line 109 to an aspirator 110 at the throat 111 of a venturi 112. A pressure reference line 113 provides a connection from the intake side of the venturi 112 to the governor 108.

In this form of the invention by way of example hydrogen in liquid form is supplied from a container 114 at 10 pounds per square inch pressure to a vaporizer 115 and then to a regulator 116. The purpose of the regulator is merely to be certain that the oxygen is at a pressure of about one-fourth pound per square inch higher than ambient. From the regulator hydrogen passes through a hydrogen supply line 117 to a separator 118, from which a pipe 119 passes the hydrogen to the entrance end of the venturi 112. Hydrogen mixing with oxygen in the throat of the venturi in a stoichiometric ratio passes to the outlet end of the venturi and then through a combined conduit 120 in which is located a conventional speed control of the butterfly type 121. From the conduit 120 the gaseous mixture flows

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to an intake 122 of a conventional combustion engine 123.

A conventional engine exhaust is exemplified by a combined passageway 124 from which the exhaust, which is a mixture of water in either steam or moist condition together with surplus hydrogen travels to a condenser 125 where the water is separated from the surplus hydrogen. Water is drawn through a pipe 126 by pump 127 and then passed through a discharge line 128 to atmosphere.

The surplus hydrogen, which is in appreciable volume, passes from the condenser 125 through a pipe 129 to the separator 118. The function of the separator is merely to extract any water which may remain present in the surplus hydrogen, such water as may be extracted being discharged through a pipe 130 by means of a pump 131 and from there passed to the discharge line 128 where it joins the water initially separated out by the condenser 125.

The surplus hydrogen from which the water has been extracted by the separator 118 passes to the pipe 119 which also receives fuel hydrogen from the hydrogen container 114.

To assist in discharging the hydrogen at the desired rate use may be made of a container 132 containing helium at a storage pressure of 2,000 pounds per square inch which, when passing through a conventional regulator 132' is used to displace hydrogen in the hydrogen container 114, the helium taking no part in the reaction nor in the system otherwise.

For operating the condenser 125 use is made of a conventional automobile radiator 133 from which a fan 134 draws air, a coolant pump 135 circulates coolant which may be water, over the condenser 125 to condense out the water as previously noted. The surplus coolant merely passes to the combustion engine for cooling in a purely conventional fashion.

Crankcase blowby vapors are carried through a blowby exhaust line 136 to the separator 118 and the blowby gas joins the surplus hydrogen as it emerges from the separator and as it is joined by the fuel hydrogen as previously described. Should there be any water vapor present in the blowby gases such water can be separated from the gases by operation of the separator 118.

Basically, the system of FIG. 5 operates in substantially the same fashion as has been described for FIG. 1 and the other forms of the invention. The expedient resorted to embodied in the venturi principle is one only of a variety of ways which can be employed to maintain a stoichiometric ratio of fuel oxygen and fuel hydrogen at different rates of flow, such rates being the result of manipulation of the speed control butterfly valve 121. It should be borne in mind that the principle of operation of the system namely maintenance of a super abundance of hydrogen as an excess gas is the principle of operation of the system of FIG. 5 as it is with the other systems, blowby is retained in the system as a closed system so that the only waste product of the system is water which is a non-atmospheric pollutant.

No special tailpipe is needed since the exhaust is not toxic. No muffler is needed because the exhaust sound level is low resulting in little more than a slight rushing sound.

Although a stoichiometric ratio is mentioned for introduction of fuel oxygen and fuel hydrogen, the salient feature of the system is there being maintained at all

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times what may apply be described as a super abundance of surplus of hydrogen gas, or possibly hydrogen mixed with some other inert gas, this surplus always being present throughout the system except in the supply lines of fuel oxygen and fuel hydrogen.

In all forms of the invention operation is begun in a substantially conventional fashion by cranking the engine thereby to create sufficient suction to draw the combustion fuel into the system where ignition is effected by spark plugs.

While the invention has herein been shown and described in what is conceived to be a practical and effective embodiment, it is recognized that departures may be made therefrom within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace any and all equivalent devices.

Having described the invention, what is claimed as new in support of Letters Patent is:

1. In a piston and cylinder type combustion engine of the open cycle type having a conventional combustion stage intake and exhaust valving and a crankcase and including a combustion chamber, a fuel system comprising an engine fuel intake including a mixing passage and conduit means from said mixing passage to said combustion chamber, open exhaust means from the engine including said exhaust valving, a first source of gas comprising oxygen as fuel, a second source of gas comprising hydrogen as fuel, a supply line from the first source of gas to the mixing passage, a supply line from the second source of gas to the mixing passage, the quantity of gas of the type supplied from said second source when in said mixing passage at a location adjacent said conduit means therefrom being a surplus several times greater than the quantity of the gas from the first source of gas which is productive of a stoichiometric ratio with said gas from the first source of gas, a portion of the exhaust means from the engine comprising a combined passageway for surplus gas and water vapor from the engine, a water separating device in said passageway adapted to separate water of combustion from said surplus gas and including a discharge means for water open to the atmosphere, a heat exchanger in said combined passageway on the upstream side of said water separating device, and a gas return line for said surplus gas leading from said water separating device to said mixing passage whereby to maintain a surplus of said gas from said second source of gas in the engine at the combustion stage.

2. A fuel system as in claim 1 including a heat exchanger in said gas return line for said surplus gas at a location between said mixing chamber and said separating device.

3. A fuel system as in claim 1 wherein said exhaust means comprises one line communicating between said engine, said separating device and said mixing chamber and another line communicating between the crankcase of said engine and said mixing chamber.

4. A fuel system as in claim 1 wherein said oxygen fuel supply and said hydrogen fuel supply are in liquid form.

5. A fuel system as in claim 1 wherein the surplus gas is hydrogen.

6. A fuel system as in claim 1 wherein the surplus gas includes a substantially noble inert gas.

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7. A fuel system as in claim 1 wherein there is a heat exchanger between the gas separated by said separating device and said exhaust means.

8. A fuel system as in claim 1 wherein there is a heat exchanger between the gas separated by said separating device and the supplies of oxygen and hydrogen fuel.

9. A fuel system as in claim 1 wherein there are heat exchangers between said exhaust means and said oxygen and hydrogen supply lines between said surplus gas

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derived from said separating device and said exhaust means, and between said surplus gas derived from said separating device and said oxygen and hydrogen supply lines.

10. A fuel system as in claim 1 wherein there is an accumulator having a relief valve therefore in communication with said exhaust means.

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# United States Patent [19]

## Swingle

[11] 3,918,263

[45] Nov. 11, 1975

### [54] HYDROGEN-FUELED INTERNAL-COMBUSTION AND STEAM ENGINE POWER PLANT

[75] Inventor: **Benny F. Swingle**, Richmond, Va.[73] Assignee: **Environmental Development Corporation**, Richmond, Va.[22] Filed: **Mar. 11, 1974**[21] Appl. No.: **450,001**

#### Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 306,436, Nov. 14, 1972, abandoned.

[52] U.S. Cl. .... **60/614; 60/620; 60/622**[51] Int. Cl.<sup>2</sup> ..... **F01K 27/00; F02G 3/02**[58] Field of Search ..... **123/1 A, 119 E; 60/620-624, 318, 597, 614, 616, 618**

#### [56] References Cited

##### UNITED STATES PATENTS

1,496,189	6/1924	Waterman .....	60/318
1,632,896	6/1927	Herr .....	60/318
3,572,297	3/1971	Murray .....	123/119 E
3,608,660	9/1971	Smith et al. ....	123/1 A
3,653,364	4/1972	Bogan .....	123/119 E

Primary Examiner—Martin P. Schwadron

Assistant Examiner—Allen M. Ostrager

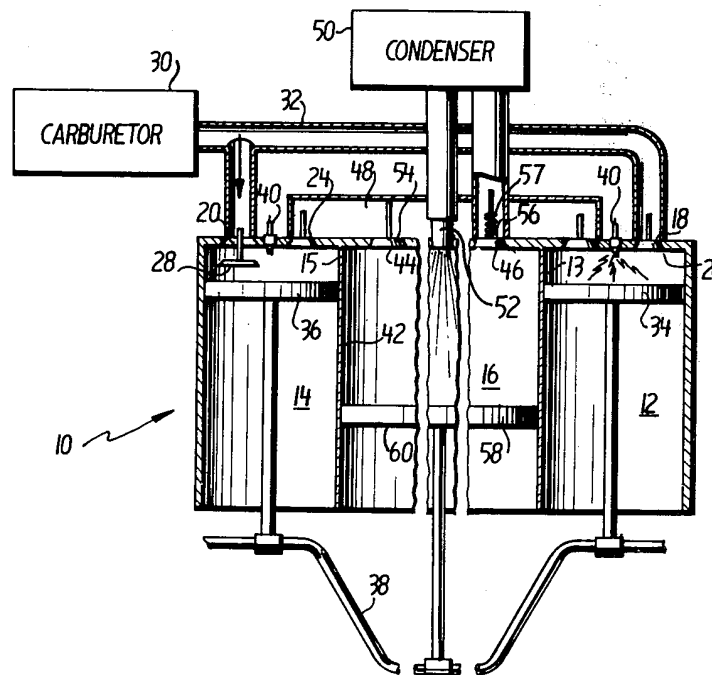
Attorney, Agent, or Firm—Griffin, Branigan and Butler

#### [57] ABSTRACT

A power plant is disclosed comprising two internal combustion engines, which are powered by a high-

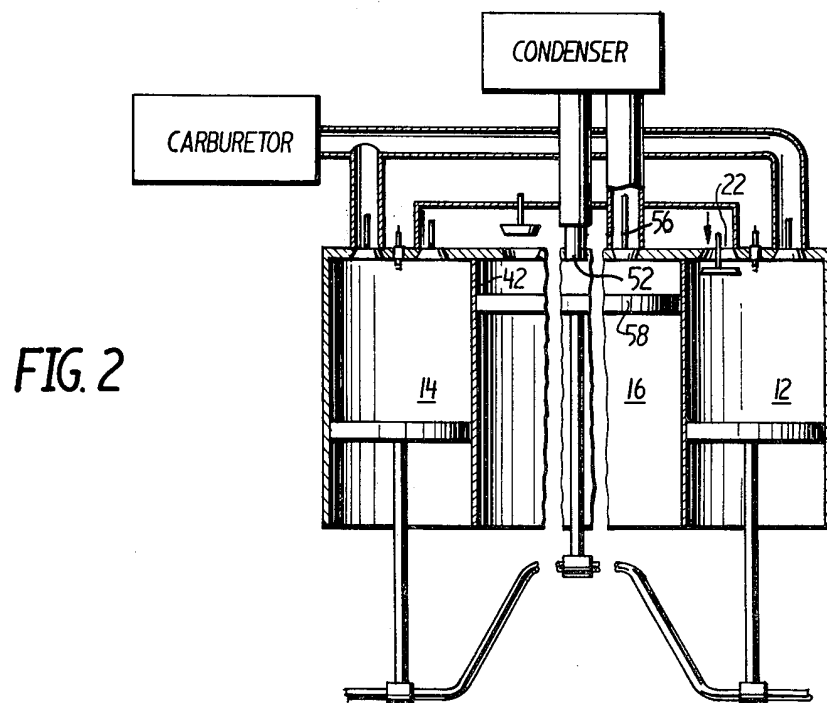
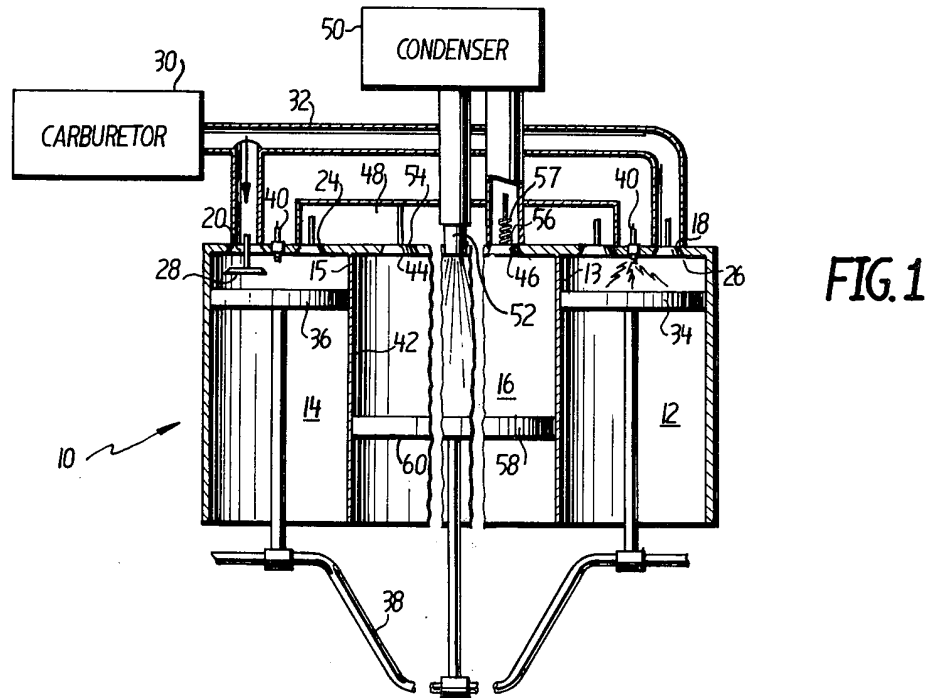
hydrogen-content fuel, and a single steam engine. A steam-engine cylinder is approximately eight times as great in volume as are internal combustion engine cylinders. A coolant jacket surrounds both the internal-combustion engines and the steam engine and an insulating jacket surrounds the coolant jacket. This power plant employs the following method to drive a rotating shaft: The hydrogen-fueled internal-combustion engines produce exhaust gases of high steam content. This steam is fed to the steam engine where it is expanded, thereby causing a reduction of both temperature and pressure. The reduction in temperature allows a heat transfer from the coolant jacket to the steam in the steam engine, and this heat, plus the reduced pressure maintain the steam in a gaseous state. The steam is then condensed. Such condensing produces even higher negative pressures in the steam cylinder for driving a piston. The power plant includes an apparatus for compensating for varying quantities of steam exhaust gases produced by the internal combustion engines with changes in engine load. The compensating apparatus mixes additional steam with the exhaust gases before they are drawn into the steam cylinder, in response to a decrease in the amount of fuel air mixture fed to the internal combustion engines. The compensating apparatus obtains additional steam from the water jacket which surrounds the power plant. Another embodiment of the power plant of this invention comprises two wankel-type internal-combustion engines and a rotary-type steam engine.

18 Claims, 15 Drawing Figures





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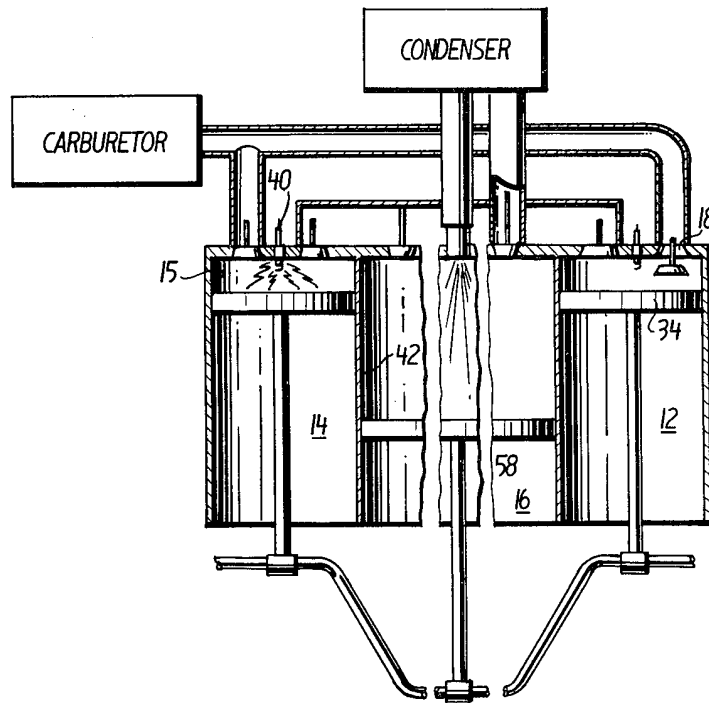


FIG. 3

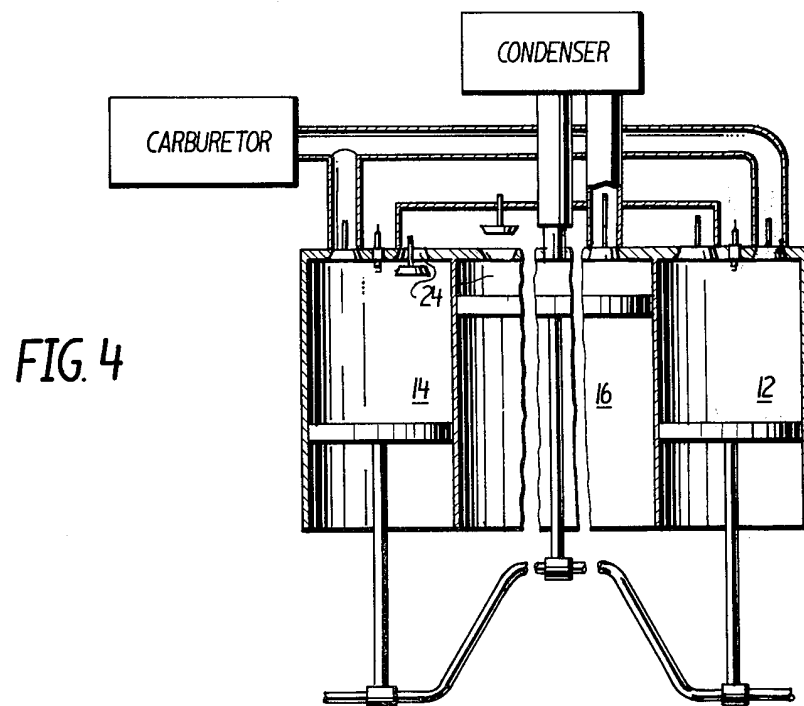
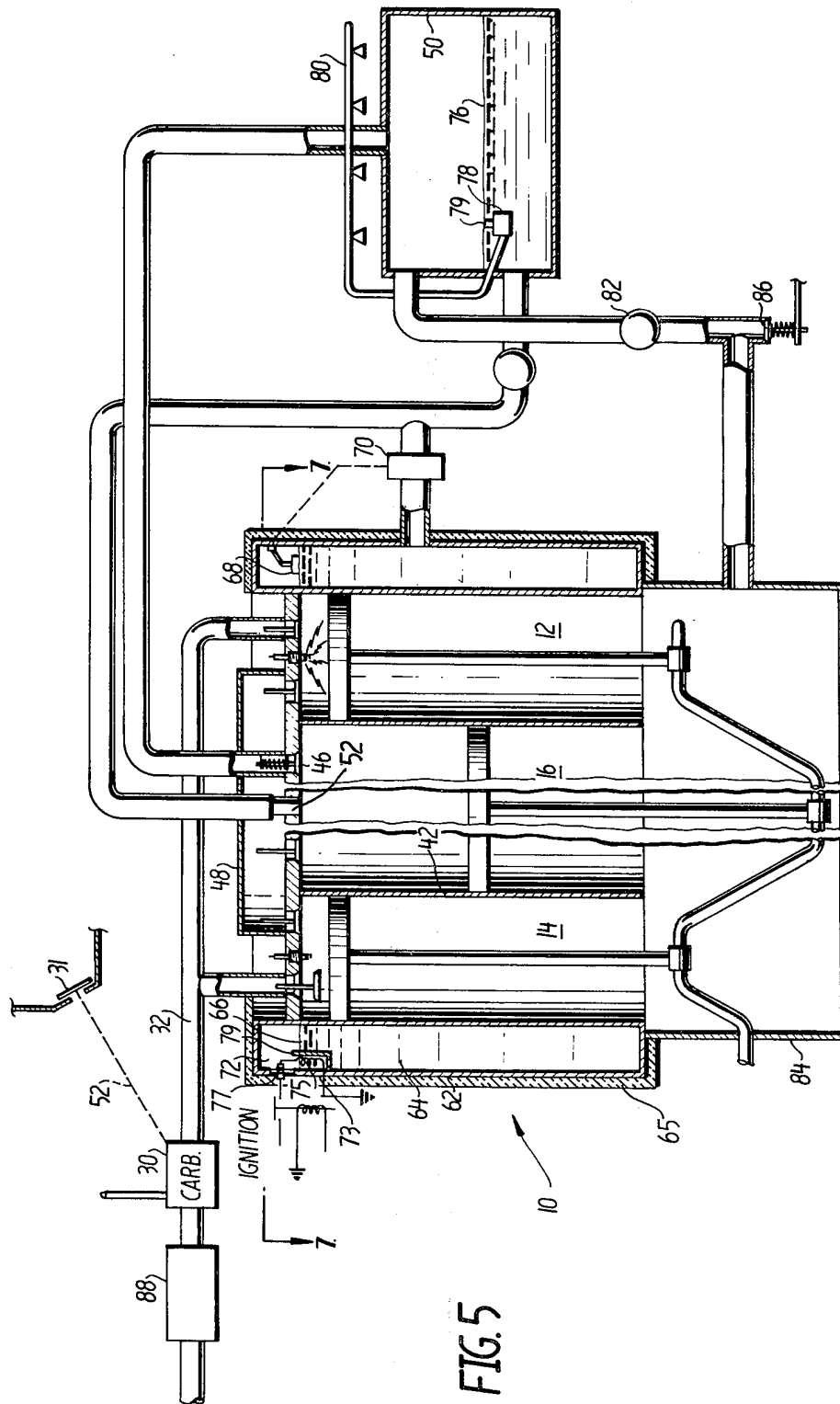


FIG. 4

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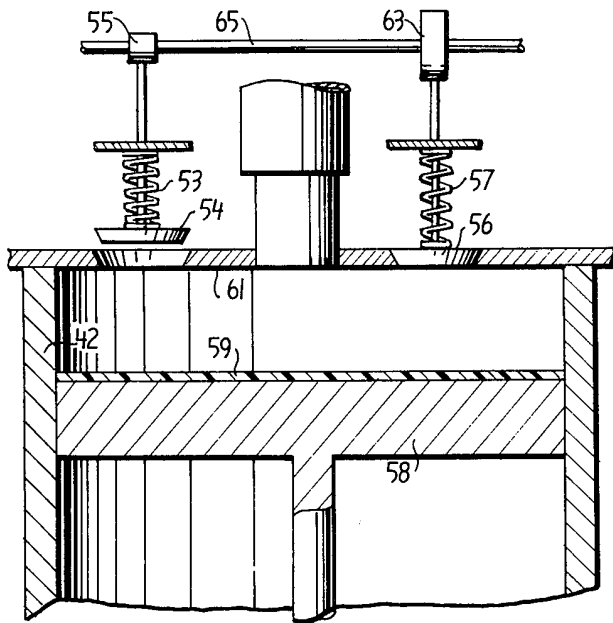


FIG. 6

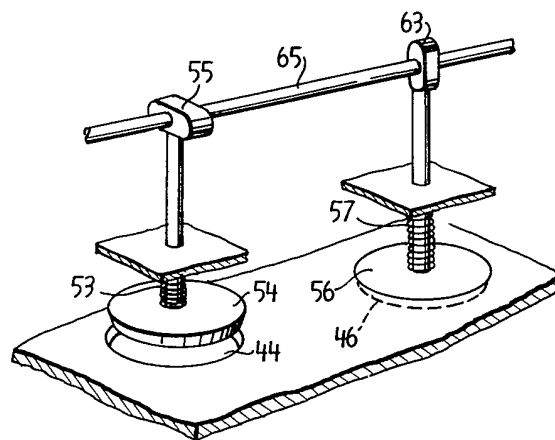


FIG. 8

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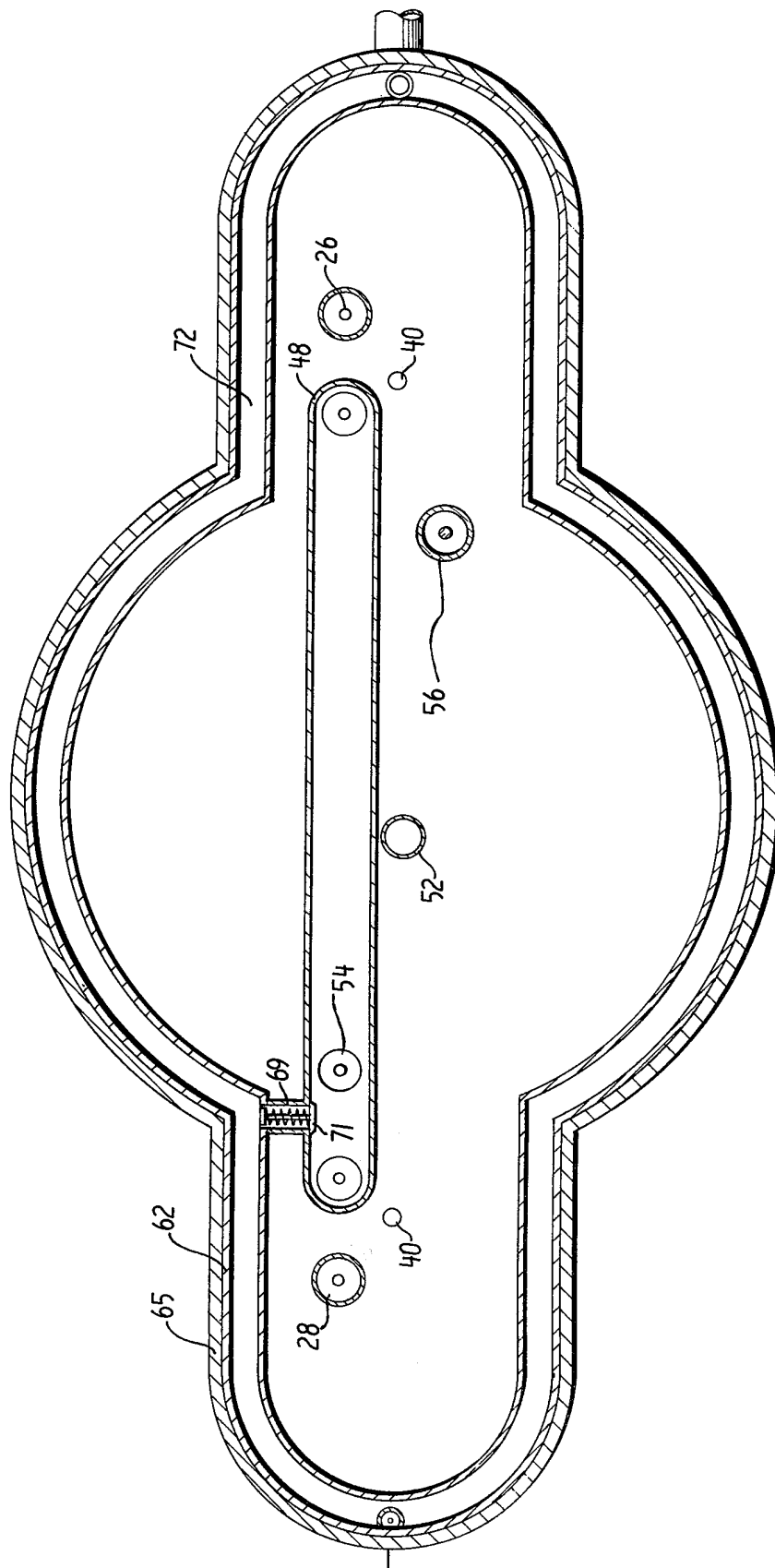


FIG. 7

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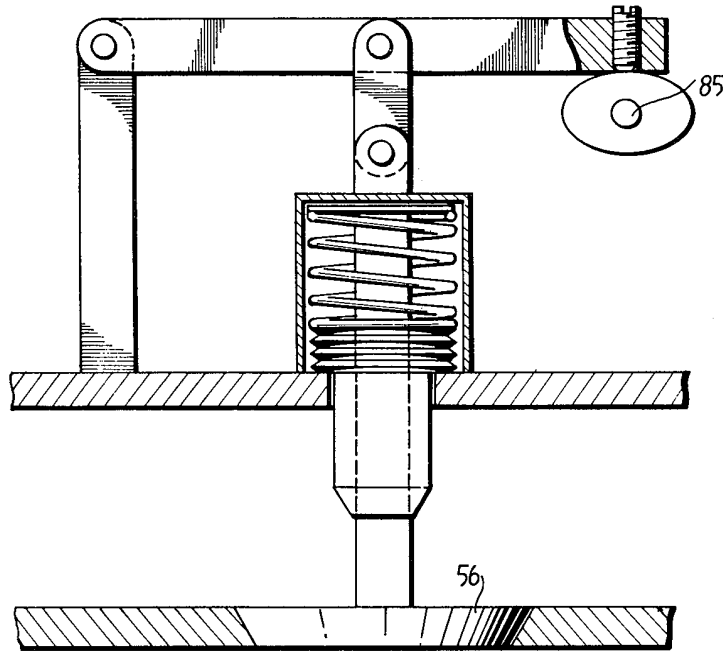


FIG. 9

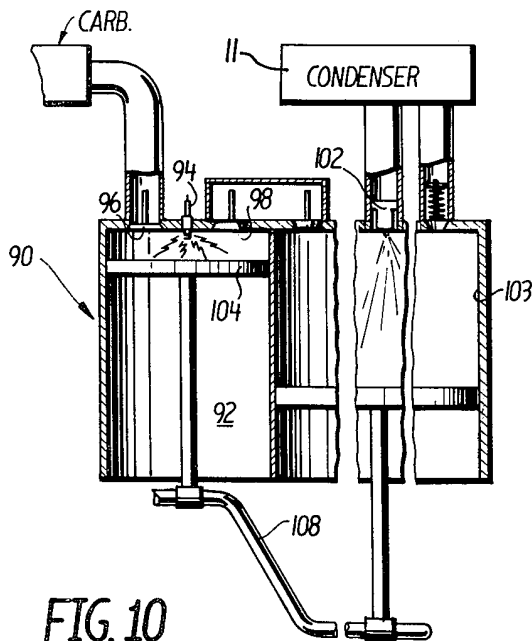


FIG. 10

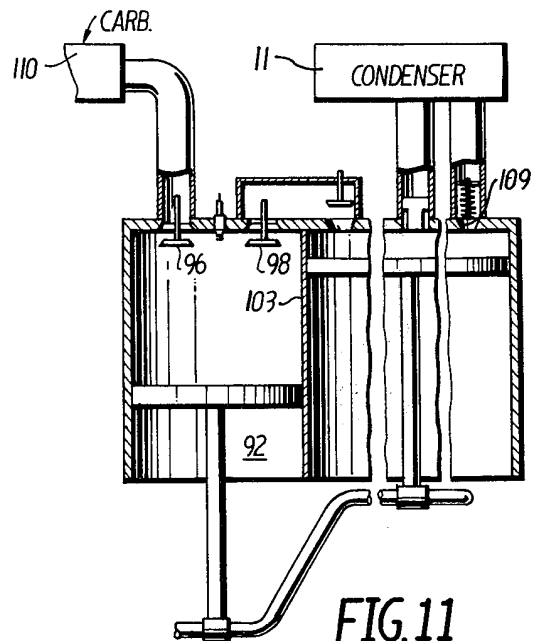
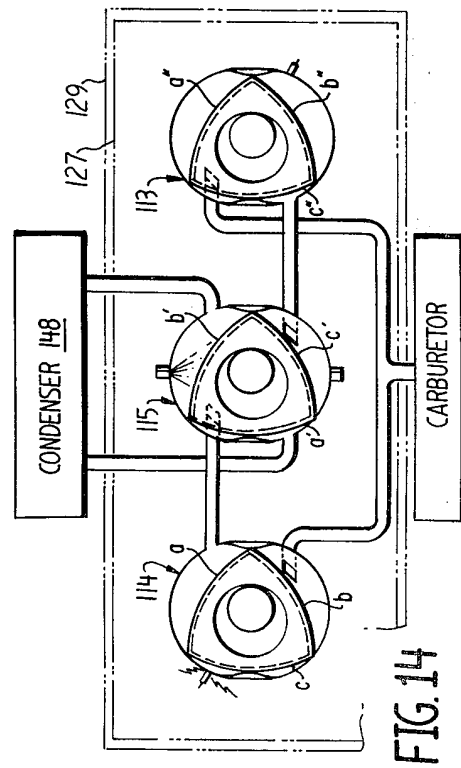
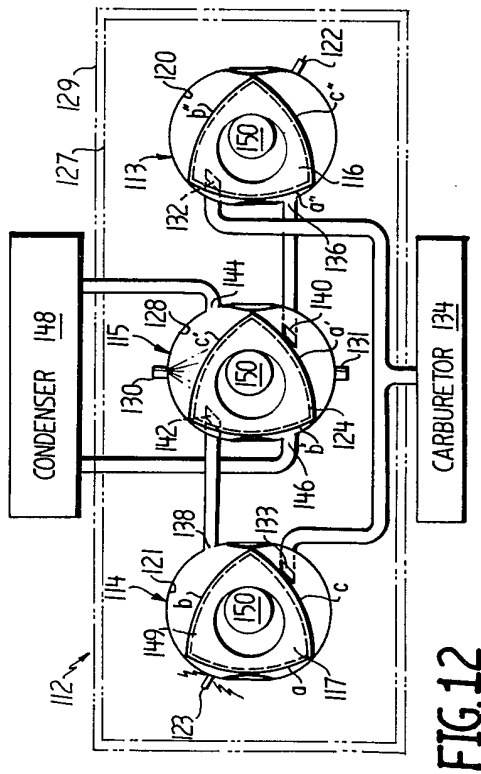
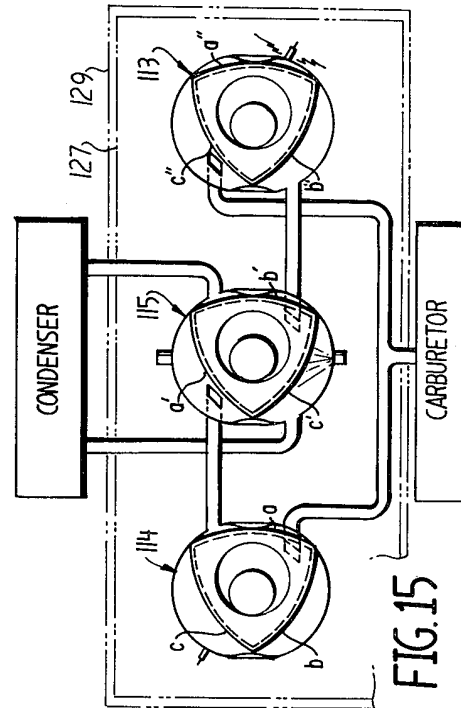
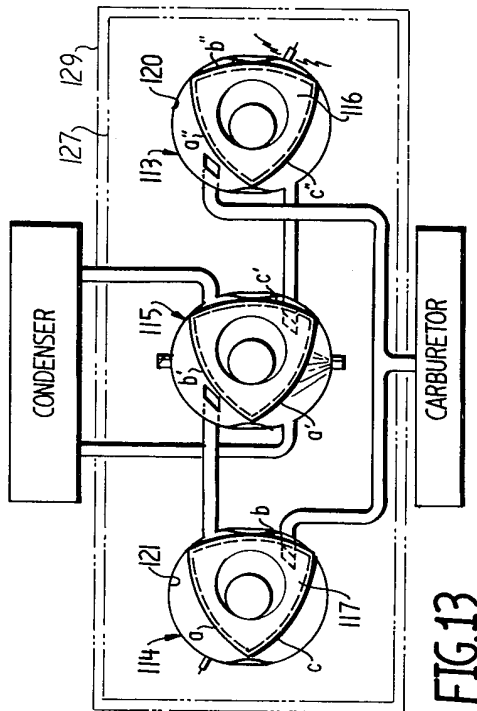


FIG. 11



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## HYDROGEN-FUELED INTERNAL-COMBUSTION AND STEAM ENGINE POWER PLANT

This application is a continuation-in-part application of U.S. Patent application serial No. 306,436, filed Nov. 14, 1972 entitled HYDROGEN-FUELED INTERNAL-COMBUSTION and STEAM ENGINE POWER PLANT, abandoned.

### BACKGROUND OF INVENTION

This invention relates broadly to the art of combination power plants comprising internal combustion (I.C.) and steam engines. More particularly, the invention concerns such a combination power plant wherein the steam engine is driven by means of condensing steam to cause a negative pressure, thereby allowing atmospheric pressure to drive a movable member.

Many power plants which combine internal-combustion engines and expansion-type steam engines have been devised wherein the internal combustion engines create steam which expands to drive the expansion-type steam engines. The following United States patents describe such power plants: Schaffers (U.S. Pat. No. 965,213), Wright (U.S. Pat. No. 1,006,167), Stocks (U.S. Pat. No. 1,011,520), Costa (U.S. Pat. No. 1,433,185), Terrenoud (U.S. Pat. No. 1,802,828), Wuehr (U.S. Pat. No. 2,217,192), Denker (U.S. Pat. No. 2,791,881), Foster (U.S. Pat. No. 3,143,850), Campbell (U.S. Pat. No. 2,202,840), Petrie (U.S. Pat. No. 3,267,661) and Straub (U.S. Pat. No. 3,426,524).

A difficulty with the devices described in most of these patents is that there is insufficient heat generated by the internal combustion engines to vaporize a sufficient amount of water for driving the expansion-type steam engines. In most of these devices, water is injected into hot exhaust gases of the internal combustion engines to vaporize this water and create expanding steam for driving the steam engines. However, what often takes place is that when water is injected into the hot exhaust gases there is contraction of the exhaust gases and an insufficient amount of steam is created to offset the effects of this contraction. Such contraction can actually cause a negative pressure rather than a positive pressure as is required to drive a piston by expanding steam. Thus, it is an object of this invention to provide an internal-combustion/steam combination power plant wherein the steam engine thereof is not primarily driven by expanding steam.

At least two prior-art U.S. patents, U.S. Pat. No. 878,925 to Woolf and U.S. Pat. No. 1,006,167 to Wright describe combination power plants wherein expanding steam (which is created by use of internal-combustion engine heat) is used to drive pistons in first directions and the steam is then condensed to create negative pressures and drive the pistons in opposite directions. Thus, these devices take advantage of the contraction phenomenon described in the previous paragraph. However, in Woolf the expanding steam is again created by injecting water into hot gases from an internal combustion engine and therefore the problem of-contraction during an expansion stroke still exists. Also, it appears that these devices create insufficient amounts of steam to properly drive the "negative-pressure" or "vacuum" strokes because there is insufficient heat given off by the internal combustion engine. Further, in these devices, back pressures are created at the exhausts of the internal combustion engines which reduce their efficiencies. It is therefore another object of this invention to provide an internal combustion/steam combination power plant which creates suffi-

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cient steam to run the steam engine portion thereof but yet which does not rely on injecting water into the exhaust gases of an internal combustion engine for the production of this steam and which is efficient in operation.

It is well known that internal combustion engines are relatively inefficient, with approximately 75% of their generated heat being ejected with exhaust gases or dissipated by cooling systems. It is yet another object of this invention to provide a power plant which gets useful work from a larger portion of the waste heat energy of an internal combustion engine than previous plants.

In recent years emphasis has been placed on creating pollution-free internal combustion engines and toward this end U.S. Pat. No. 3,572,297 to Murray and U.S. Pat. Nos. 3,608,529 and 3,608,660 to Smith disclose hydrogen-fueled internal combustion engines. However, none of these apparatus uses the steam exhaust created by these hydrogen-fueled internal combustion engines to drive steam engines. It is therefore another object of this invention to provide a method and apparatus for employing the steam created by hydrogen-fueled internal combustion engine to drive steam engines.

### SUMMARY OF THE INVENTION

According to principles of this invention a hydrogen-fueled internal combustion engine is combined with an "inverse-acting" or "negative pressure" steam engine having a cylinder which is approximately eight times as large in size as the internal combustion engine cylinder. A coolant jacket surrounds both the internal combustion engine and the steam engine and an insulating jacket surrounds the coolant jacket. The hydrogen-fueled engine produces naturally high-steam-content exhaust gas. This exhaust gas is transferred to the steam engine where it is expanded, thereby causing a reduction of both temperature and pressure. The reduction of temperature allows a heat transfer from the coolant jacket to the steam in the steam engine, and this heat, plus the reduced pressure, maintains the steam in a gaseous state. The steam is then condensed, thereby creating negative pressures in the steam engine and allowing atmospheric pressure to drive a movable member of the steam engine. The principles of this invention can be used for piston-type power plants as well as rotary (e.g., wankel) power plants.

### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings in which reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention in a clear manner.

FIGS. 1-4 are simplified cutaway side views of a piston-type power plant employing principles of this invention at various time intervals in an operational cycle wherein the internal combustion engine thereof is a four-cycle engine and wherein the size of the steam engine is reduced by inclusion of break lines;

FIG. 5 is a more detailed cutaway side view of the apparatus of FIGS. 1-4;

FIG. 6 is a diagrammatic side view of the stem cylinder chamber of the apparatus of FIGS. 1-5;

FIG. 7 is a sectional view taken on line 7-7 of FIG. 5;



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FIG. 8 is an isometric view showing the camshaft of FIG. 6 driving steam cylinder chamber valves;

FIG. 9 is a partially cutaway side view of a modified mechanism for driving a steam-cylinder exhaust valve;

FIGS. 10 and 11 are simplified cutaway side views of a piston-type power plant wherein the internal combustion engine thereof is a two-cycle engine, the views being taken at different time intervals in an operational cycle; and,

FIGS. 12-15 are schematic views of a rotary (wankel) type power plant which employs principles of this invention at various time intervals in an operational cycle.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1-5, a power plant 10 comprises right and left internal combustion engines 12 and 14 and a steam engine 16.

The right and left internal combustion (I.C.) engines 12 and 14 respectively define I.C. cylinder chambers 13 and 15 which respectively have fuel inlet openings 18 and 20 and exhaust-gas outlet openings 22 and 24. Fuel flow through the fuel inlet openings 18 and 20 is controlled by means of fuel-inlet valves 26 and 28. A high-hydrogen content fuel is fed from a carburetor 30 in response to depression of an accelerator pedal 31 (FIG. 5) through an intake manifold 22 to the fuel inlet openings 18 and 20. Some examples of suitable high hydrogen content fuels for use in this invention are propane, butane, methane, natural gas and pure hydrogen.

Positioned inside the I.C. cylinder chambers 13 and 15 respectively are I.C. pistons 34 and 36 which are rotatably attached to a crankshaft 38. Right and left sparkplugs 40 are mounted at the upper ends of the I.C. cylinder chambers 13 and 15.

The steam engine 16 defines a steam cylinder chamber 42 which is between 6 and 10 times greater in volume than either of the I.C. cylinder chambers 13 and 15, and in the preferred embodiment is approximately eight times as great. It is presently thought that if the steam cylinder chamber's volume were less than six times as great as that of the I.C. cylinder chamber there would not be a sufficient reduction in steam temperature to obtain a meaningful transfer of heat to the steam as explained below. The steam cylinder chamber 92 has a steam intake opening 44 and an exhaust opening 46. The steam intake opening 44 is connected by means of a steam transfer manifold 48 to the exhaust gas outlet openings 22 and 24. The steam exhaust opening 46 is connected to a condenser 50 and the condenser 50 is, in turn, connected to a water-injection system 52, which communicates with the inside of the steam cylinder chamber used to inject water directly into the steam cylinder. The water injection system responds to depression of the accelerator pedal 31 (FIG. 5) by injecting more water into the steam of cylinder chamber 42. A steam-in valve 54 controls steam flow through the steam intake opening 44 and an exhaust valve 56 controls exhaust flow through the exhaust opening 46.

With reference to FIGS. 6 and 8 (FIG. 8 being an isometric which is arranged to show cam lobes) a spring 54 biases the steam-in valve 54 toward an open position and a spring 57 biases the exhaust valve 56 toward a closed position. The cam lobe 55, mounted on a cam shaft 65, operates on the steam-in valve 54 to positively

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close this valve; while the spring 53 opens this valve when it is released by the cam lobe 55. The cam lobe 63 operates on the exhaust valve 56 to hold this valve in a closed position; and the spring 57 also acts to hold this valve in a closed position.

It should be noted that the cam lobes 55 and 63 each have two faces. Two faces are necessary because the steam engine 16 is a two cycle engine, whereas I.C. engines 12 and 14 are four cycle engines.

The steam cylinder chamber 42 is much larger (6 to 10 times) than the I.C. cylinder chambers 13 and 15 so that exhaust gases can be transferred from the I.C. cylinder chambers to the steam cylinder chamber at a below atmospheric pressure. In the preferred embodiment the diameter of the steam cylinder chamber 42 is about eight times as great as that of the I.C. cylinder chambers 13 and 15, with this size difference being apparent from FIG. 7.

A steam piston 58 is positioned inside the steam cylinder chamber 42 and is rotatably connected to the crankshaft 38.

The fuel-inlet and exhaust-outlet valves of the internal combustion engines 12 and 14, as well as the water injection system 52 of the steam engine 16 are also operated by the camshaft 65, although this is not shown in the drawings.

FIGS. 5 and 7 show the apparatus of FIGS. 1-4 in more detail and depict various refinements to the basic apparatus of FIGS. 1-4.

It can be seen in FIG. 5 that the power plant 10 is surrounded by a water jacket 62 which is, in turn, surrounded by an insulating jacket 65. Water 64 is maintained at a fixed level 66 by means of a float 68 which controls a water-in valve 70. The water 64 absorbs heat from the internal combustion engines 12 and 14 and steam develops in a small open space 72 about the water level 66. In FIG. 7 it can be seen that the open space 72 communicates with the steam transfer manifold 48 by means of a passage 69 and a spring-biased, normally-closed valve 71.

The purpose of the valve 71 is to compensate for varying amounts of steam which are produced by the internal combustion engines 12 and 14 for filling the fixed-volume steam cylinder chamber 42. In this regard, at high power engine outputs the right and left I.C. engines 12 and 14 produce a sufficiently large amount of steam to produce desirable pressure in the steam cylinder chamber 42; but at lower power outputs there is not sufficient steam produced for the steam cylinder chamber 42. When this happens a sufficiently high negative pressure is produced inside the steam transfer manifold 48 and the spring-biased valve 71 opens to relieve this high negative pressure. In an unillustrated embodiment a variable bias is provided for the valve 71 which is driven by the cam shaft to increase the negative pressure required to operate the valve 71 at bottom-dead-center of the steam piston. When the power plant 10 is first started, and the water 64 is relatively cool, there is little, or no, steam available inside the open space 72. Thus, an electric flash heater 73, having a heating element 75, which is responsive to a pressure switch 77, is provided to create steam relatively quickly because it must only heat that water which enters an insulated enclosure 79 through a small opening in the bottom of the enclosure 79. After the power plant 10 has been running for a time the pressure switch 77 cuts off the flash heater 73.

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The water 64 has the additional purpose of transferring heat from the I.C. engines 12 and 14 to the steam cylinder chamber 42, as will be described below.

It can be seen in FIG. 5 that steam and water passing through the exhaust opening 46 enter the condenser 50. Any steam which remains in the exhaust is condensed by the condenser 50 and forms as water 76 at the bottom of the condenser 50. Surplus water enters a pipe 79 and is pumped by means of a pump 78 into a water spray nozzle 80. The nozzle 80 sprays this water onto the outside of the condenser 50, where it evaporates and thereby removes heat from the condenser 50. A water supply pump 81 furnishes a continuous pressurized supply of water to the water-in valve 70 and to the water injection system 52. A vacuum pump 82 continuously pumps gases out of the condenser 50 and presses these gases toward a crankcase 84. The atmosphere in the crankcase 84 is maintained at a desirably high fixed pressure by means of a spring-biased relief valve 86 which opens automatically at the desired pressure. The reason for pressurizing the crankcase 84 is to balance the effects of a super charger 88 which is used to increase the pressure of the fuel/air mixture entering the I.C. cylinder chambers 13 and 15. The purpose of the super charger 88 is to aid in pressing a sufficient amount of fuel into the I.C. engines 12 and 14 for providing sufficient steam to drive the steam engine 16; however, these features are embellishments and not essential to the overall operation of the invention.

Explaining now the overall sequence of operation of the power plant of FIGS. 1-8, generally, the hydrogen fuel which drives the right and left I.C. engines 12 and 14 creates primarily steam exhaust gases which are transferred to the steam engine 16. In the steam engine 16, the exhaust steam is expanded so that it absorbs heat from the heated water 64 (FIG. 5) in the water jacket 62. The steam is then condensed to cause a vacuum power stroke.

With particular reference to FIGS. 1-4, FIG. 1 depicts the power plant at the beginning of a cycle. In this position the right I.C. engine 12 is beginning a power stroke, the left I.C. engine 14 is beginning an intake stroke and the steam engine 16 is beginning a "vacuum (power) stroke".

With reference to the right I.C. engine 12, the carburetor 30 has just fed a high-hydrogen content fuel air mixture through the fuel inlet opening 18 and the fuel inlet valve 26 has closed. The right sparkplug 40 is firing in FIG. 1, as indicated by jagged lines, thereby causing ignition of the high-hydrogen content fuel/air mixture in the I.C. cylinder chamber 13.

With reference to the steam engine 16, the steam cylinder chamber 42 is full of steam at a pressure of approximately 8 P.S.I.A. (absolute) and at a temperature of approximately 150°F. When it first began to receive this steam from the left I.C. engine 14 through the steam intake opening 44 the steam was at a pressure of 15 P.S.I.A. and a temperature of 2,300°F; however, the steam cylinder chamber 16, being eight times as great in volume as the left I.C. engine cylinder chamber 15, expanded the steam in the transfer so that its temperature was reduced to approximately 150°F. The steam remained in a gaseous state however, due to the reduced pressure and by absorbing heat from the water jacket 62. In this regard, the water in the water jacket 62 is maintained at a temperature of approximately 350°F. This water receives heat from combustions in

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the I.C. engines. It should also be mentioned that engine oil temperature is also maintained at 350°F and heat is transferred from this to the steam in the steam cylinder through the piston head.

The cam shaft 65 (FIGS. 6 and 8) is positioned such that the steam-in valve 54 is now being held closed by the cam lobe 55 but the exhaust valve 56 is allowed to open. However, the exhaust valve 56 is being held closed by the spring 57. Water is being injected by the water-injection system 52 into the steam cylinder chamber 42 which causes condensation of steam thereby creating a negative pressure in the steam cylinder chamber 42. Thus, atmospheric pressure operates on a surface 60 of the steam piston 58 to drive it upwardly.

The left I.C. engine 14 is just beginning its induction stroke. That is, the fuel inlet valve 28 is open so that a high-hydrogen content fuel/air mixture can enter the cylinder chamber through the fuel inlet opening 20 and, as the I.C. piston 36 is pulled downwardly by the crankshaft 38, the hydrogen fuel is drawn into this chamber.

Turning now to FIG. 2 (one quarter of a cycle later), the right I.C. engine 12 is now beginning its exhaust stroke, the steam engine 16 has just ended its vacuum (power) stroke and is beginning its induction stroke and the left I.C. engine 14 is beginning its compression stroke.

Although not shown in FIG. 2, the steam engine exhaust valve 56 was forced open (against the bias of spring 57, FIGS. 6 and 8) by condensed water and residual gases in the steam cylinder chamber 42 when the steam piston 58 approached the top 61 of the steam cylinder chamber 42 at the end of the vacuum stroke. In this regard, with reference to FIG. 6, the steam piston 58 has a layer 59 of a relatively soft plastic, such as Teflon, on the top surface thereof to allow contact between the top surface of the piston and the top 61 of the steam cylinder 42. Once the water and exhaust gases were forced past the exhaust valve 56, the exhaust valve 56 was closed automatically by spring 57, and was thereafter held closed by the cam lobe 63 as shown in FIG. 6. The cam lobe 63 will continue to hold this valve closed through the induction stroke. Eventually the water and exhaust gases flow into the condenser 50. It can also be seen in FIG. 2 that exhaust steam from the right I.C. engine 12 will be transferred through the exhaust gas outlet opening 22 and the steam intake opening 44 to the steam cylinder chamber 42.

Referring now to FIG. 3, (one half of a cycle) the right I.C. engine 12 is beginning its induction stroke, the steam engine 16 is beginning a power stroke. The I.C. piston 34, as it moves downwardly, draws high hydrogen content fuel from the carburetor 30 through the fuel inlet opening 18. Water is being injected into the steam cylinder chamber 42 by means of the injection system 52, thereby condensing steam in the steam cylinder chamber 42 and creating a negative pressure inside the steam cylinder chamber 42 which allows atmospheric pressure to drive the steam piston 58 upwardly. The left sparkplug 40 is firing thereby igniting the hydrogen fuel in the left I.C. engine cylinder chamber 15.

In FIG. 4, (three quarters of a cycle) the right internal combustion engine 12 is beginning a compression stroke, the steam engine 16 has completed a second vacuum (power) stroke and is beginning a second in-

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duction stroke, and the left I.C. engine 14 is beginning an exhaust stroke. In this regard, steam, which forms the exhaust gases of the left I.C. engine 14, will be transferred through the exhaust gas outlet opening 24 and the steam intake opening 44 to the steam cylinder chamber 42.

One quarter of a cycle later we return to the beginning of the cycle at FIG. 1 and the cycle is repeated.

It should be noted that the steam piston 58, while withdrawing, pulls a partial vacuum in the steam cylinder chamber 42 and in an exhausting I.C. cylinder chamber due to the relatively large size of the steam cylinder chamber 42. The amount of vacuum is controlled somewhat by the valve 71 (FIG. 7) which, as mentioned above, may have a variable bias controlled by the cam shaft. In any event the work required to pull this partial vacuum is substantially recovered during the vacuum (power) stroke of the steam engine. Further, by positively drawing the exhaust gases out of the I.C. engine, the I.C. engine's efficiency is increased.

An interesting feature of this invention is that it operates similarly as did a steam engine built by Thomas Newcomen of England in 1712. That is, it employs a vacuum stroke without a pressure stroke as do most modern steam engines. It should be understood that such a system is enhanced by the use of hydrogen fuel which creates steam as exhaust gases. Also it should be understood that this system is superior to combination power plants wherein expanding steam is used to drive pistons because it does not require an undue amount of heat for converting water to steam.

Further, this system uses exhaust gases which are naturally generated by an internal combustion engine for performing work, thereby increasing its efficiency over those of internal combustion engines which simply discard exhaust gases.

FIG. 9 depicts another method of controlling the steam engine exhaust valve 56, wherein a cam shaft 85, which drives all of the other intake and exhaust valves of the power plant 10, as well as the water injection system 52, positively lifts the valve 56 at appropriate time intervals. In this embodiment the valve 56 is held closed by a spring.

It will be appreciated by those skilled in the art that it is possible to open the exhaust valve 56 when the steam piston 58 is at the bottom of its stroke (as shown in FIG. 1) and then perform all of the steam condensing in the condenser 50 to power a vacuum stroke rather than condensing by injecting water into the steam cylinder chamber 42. And, in fact, such a procedure is employed in another embodiment of this invention although not depicted herein.

FIGS. 10 and 11 depict a power plant 90 which is similar to the power plant 10 of FIGS. 1-5; however, in this embodiment a single internal combustion engine 92 is a two cycle engine rather than a four cycle engine.

In FIG. 10 the internal combustion engine 92 is beginning a power stroke. Its sparkplug 94 is firing, and its intake and exhaust valves 96 and 98 are both closed. A steam engine 100 is beginning its vacuum, or power, stroke. An injection system 102 is injecting water into steam inside a cylinder chamber 103 of the steam engine 100 to condense steam therein. Thus, both an I.C. piston 104 and a steam piston 106 drive a crankshaft 108 on this stroke.

In FIG. 11 (one half of a cycle later), the I.C. engine 92 is in its induction and exhaust mode in that the in-

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take valve 96 and the exhaust valve 98 are open and the steam engine 100 is in its induction mode. The steam piston has just finished forcing condensed water and gases through a normally closed, spring-biased valve 109, toward a condenser 111. A high-hydrogen content fuel is entering the cylinder chamber of the I.C. engine 92 from a carburetor 110 and exhaust steam is being transferred from the cylinder chamber of the I.C. engine 92 to the cylinder chamber 103 of the steam engine 100.

A similar steam cylinder/I.C. cylinder volume ratio exists for the two-cycle I.C. engine of FIGS. 10 and 11 as for the four-cycle system of FIGS. 1-5. Also a water jacket is similarly employed, although not depicted in the drawings.

Thus, essentially the same method that was used to drive the power plant of FIGS. 1-5 is also used to drive the power plant of FIGS. 10 and 11. That is, an internal combustion engine is driven on a high hydrogen content fuel and steam exhaust from the internal combustion engine is expanded and used to produce a vacuum (power) stroke in a steam engine.

Turning now to FIGS. 12-15, there is depicted therein a wankel-type rotary power plant 112 which operates in a manner similar to the manner in which the piston-type power plant of FIGS. 1-4 operates.

The wankel-type rotary power plant 112 comprises right and left internal combustion engines 113 and 114 and a steam engine 115.

The I.C. engines 113 and 114 respectively include I.C. rotary pistons 116 and 117, I.C. chambers 120 and 121 and spark plugs 122 and 123.

The steam engine 115 includes a steam rotary piston 124, a steam chamber 128 which is approximately eight times as large as the I.C. chambers 120 and 121, although it does not appear to be so in the drawings. The steam engine also includes first and second water injection systems 130 and 131.

Also included in the wankel-type rotary power plant 112 is a water jacket enclosing the I.C. and steam engine (indicated by a box 127) and an insulative jacket enclosing the water jacket (indicated by a box 129). The water jacket 127 and the insulative jacket 129 have the same functions as the water and insulative jackets 62 and 65 of FIG. 5.

The I.C. chambers 120 and 121 have intake ports 132 and 133 interconnected with a carburetor 134 which furnishes a high-hydrogen-content fuel. The I.C. chambers 120 and 121 have exhaust ports 136 and 138 which are respectively interconnected with steam intake ports 140 and 142 of the steam engine 115. And the steam engine 115 has exhaust ports 144 and 146 which are interconnected with a condenser 148.

The I.C. intake ports 132 and 133 and the steam intake ports 140 and 142 are respectively located at the end walls of the I.C. chambers 120 and 121 and the steam chamber 128. End seal strips 149 are on the end faces of the rotary pistons 116, 117 and 124 which make contact with end walls of the chambers 120, 121 and 128. The intake ports 132, 133, 142 and 140 are positioned such that there is little or no respective overlapping between intake and exhaust portions of cycles.

It should be understood that the rotors 116, 117 and 124 have internal teeth which respectively mesh with external teeth of a single shaft 150, for driving the shaft. In this regard, FIGS. 12-15 depict a schematic view wherein the various engines are shown in phase,

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positionally, side-by-side, whereas, in fact, they are lined up along the single shaft 150 and are not necessarily in phase positionally. Further structures of the engines 113–115 are similar to normal wankel-type rotary engines and therefore are not explained in detail herein.

To aid in explaining the operation of the rotary power plant 112, generally, the hydrogen fuel which drives the right and left I.C. engines 113 and 114 creates primarily steam exhaust gases which are transferred to the steam engine 115. In the steam engine 115, the exhaust steam is expanded so that it absorbs heat from the heated water in the water jacket 127. The steam is then condensed to cause vacuum power strokes.

More particularly, in FIG. 12 (beginning of cycle) the spark plug 123 of I.C. engine 114 is firing to ignite high-hydrogen fuel so that face *a* is beginning a power stroke. Face *b* is simultaneously beginning to exhaust steam through the exhaust port 138 and face *c* is about to begin a compression stroke after receiving a hydrogen fuel/air mixture from the carburetor 134.

Face *b'* of the steam engine 115 is completing a vacuum power stroke by pressing condensed water through an exhaust port 146 to the condenser 148 and is about to begin an induction stroke by drawing steam from the left I.C. engine 114 through the steam intake port 142. Since the steam chamber 128 is eight times as large as the I.C. chambers, such induction produces a decrease in the pressure of and a lowering of the temperature of the steam. The temperature is reduced below the temperature of water in the water jacket and the steam absorbs heat from the water. Face *c'* is in the midst of a vacuum power stroke inasmuch as the water injection system 130 is injecting water into the steam chamber 128 to condense steam trapped by the face *c'*. It is noted that this trapped steam already has access to the condenser 148 through the exhaust port 144, and in some cases it is not necessary to inject water into the steam cylinder 128. Face *a''* is just completing an induction stroke wherein it is receiving exhaust steam from the I.C. engine 113.

With regard to the right I.C. engine 113, face *a''* is completing an exhaust stroke and about to begin an induction stroke, face *b''* is beginning a compression stroke and face *c''* is completing a power stroke.

Outlining now the positions of the respective faces of the rotor pistons of FIGS. 12–15:

FIG. 13 (one sixth of a cycle)

I.C. Engine 114

Face *a* — completing power stroke

Face *b* — completing exhaust stroke

Face *c* — completing compression stroke

Steam Engine 115

Face *a'* — during vacuum stroke

Face *b'* — completing induction stroke

Face *c'* — completing vacuum stroke

I.C. Engine 113

Face *a''* — completing induction stroke

Face *b''* — beginning power stroke

Face *c''* — beginning exhaust stroke

FIG. 14 (two sixths of a cycle)

I.C. Engine 114

Face *a* — beginning exhaust stroke

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Face *b* — completing induction stroke

Face *c* — beginning power stroke

Steam Engine 115

Face *a'* — completing vacuum stroke

Face *b'* — during vacuum stroke

Face *c'* — completing induction stroke

I.C. Engine 113

Face *a''* — beginning a compression stroke

Face *b''* — completing a power stroke

Face *c''* — completing an exhaust stroke

FIG. 15 (three sixths of a cycle)

I.C. Engine 114

Face *a* — completing an exhaust stroke

Face *b* — beginning a compression stroke

Face *c* — completing a power stroke

Steam Engine 115

Face *a'* — completing an induction stroke

Face *b'* — completing a vacuum stroke

Face *c'* — during a vacuum stroke

I.C. Engine 113

Face *a''* — beginning a power stroke

Face *b''* — beginning an exhaust stroke

Face *c''* — completing an induction stroke

It should be noted that in the various embodiments of this invention, heat, which is normally thrown off as waste in conventional internal combustion engines, is utilized to maintain water as steam at reduced pressure until it is condensed. Also, the heat in the exhaust gases themselves is used to maintain the water as steam until it is condensed. Still further, the steam engine in each embodiment draws a partial vacuum on the exhausts of the I.C. engines which improves I.C. engine scavenging. All of these factors combine to provide increased efficiency of the power plants of this invention over those of conventional I.C. engines.

While the invention has been particularly shown and described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention. For example, during the vacuum/power stroke of the steam engine 16 (FIGS. 1–4), all, or part of, the steam condensing could take place in the condenser 50 rather than in the cylinder chamber 42, as described above. Further, spring loaded valves, similar to valve 56 of the FIGS. 1–5 embodiment, could be mounted in the steam engine exhaust ports 144 and 146 of the FIGS. 12–15 embodiment. Further, a multiple stage vacuum steam engine could be employed rather than a single stage, as is depicted and described herein.

I claim:

1. A method of driving a working member comprising the steps of:

igniting a fuel of high hydrogen content in an internal combustion chamber thereby producing a large amount of steam which expands said internal combustion chamber to drive said working member;

transferring said steam to a steam chamber and therein expanding the volume of said chamber a sufficient amount to reduce the steam pressure therein to a negative pressure and thereby reduce its temperature;

transferring waste heat from said internal combustion engine to said steam in said steam chamber; thereafter condensing said transferred steam thereby producing a still greater negative pressure in said steam chamber whereby atmospheric pressure con-

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tracts said steam chamber to drive said working member.

2. A method as claimed in claim 1 wherein said transferred steam is condensed in said steam chamber by means of injecting water into said chamber.

3. A method as claimed in claim 2 wherein said steam chamber includes a separate condenser.

4. A method as claimed in claim 1 wherein is included the additional step of inserting additional steam into said steam as it is transferred from said internal combustion chamber to said steam chamber.

5. A method as claimed in claim 4 wherein said additional steam is obtained by heating water with waste heat generated by the ignition of said fuel in said internal combustion chamber and wherein said heated water surrounds said internal combustion chamber and said steam chamber for transferring said heat from said internal combustion engine to said steam in said steam chamber.

6. A power plant comprising:  
a driven member;

an internal combustion engine, said internal combustion engine including:

a member for defining a combustion chamber having a fuel inlet opening and an exhaust-steam outlet opening;

a carburetor means for feeding a high-hydrogen-content fuel to said fuel inlet;

an igniting means for igniting said high-hydrogen-content fuel and thereby causing combustion of said fuel inside said combustion chamber; and  
a steam engine, said steam engine including:

a member for defining a steam chamber having a steam inlet opening and an exhaust outlet opening wherein said steam inlet opening is interconnected with said combustion-chamber exhaust-steam outlet opening so that steam leaving said combustion chamber through said exhaust-steam outlet opening enters said steam chamber through said steam inlet opening, said steam chamber having a volume which is from six to 10 times greater than the volume of said combustion chamber;

a condenser means for condensing said steam which enters said steam chamber through said steam inlet opening, thereby causing a negative pressure inside said steam chamber;

a movable member positioned inside said steam chamber, which is attached to said drive member, and which is motivated by a pressure differential between said negative pressure and a pressure related to atmospheric pressure, to drive said driven member;

a heat-transfer means for transferring waste heat from said combustion chamber to said steam in said steam chamber.

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7. A power plant as claimed in claim 6 wherein said internal combustion engine and said steam engine are piston-type engines.

8. A power plant as claimed in claim 7 wherein there are two piston-type internal combustion engines, each of said engines being a four cycle engine.

9. A power plant as claimed in claim 7 wherein is further included means for mixing additional steam with said exhaust steam which is transferred from said combustion chamber to said steam chamber, with the amount of said additional steam being dependent upon the load which said power plant motivates.

10. A power plant as claimed in claim 9 wherein: is further included:

a water tank for absorbing waste heat generated by said internal combustion engine and thereby producing steam and said additional steam is obtained from said water tank; and

wherein said water tank forms said heat transfer means by surrounding said combustion and steam chambers.

11. A power plant as claimed in claim 10 wherein is further included an electric flash heater in said water tank for aiding in creating said additional steam.

12. A power plant as claimed in claim 7 wherein said condensing means includes a means for injecting water into said steam chamber for condensing steam in said steam chamber.

13. A power plant as claimed in claim 7 wherein said steam chamber includes a piston cylinder portion and a condenser portion which is separate from said piston cylinder portion but which is in communication with said piston cylinder.

14. A power plant as claimed in claim 13 wherein said condenser means includes a means for injecting water into said piston cylinder portion for condensing steam in said piston cylinder portion.

15. A power plant as claimed in claim 7 wherein there is one piston-type internal combustion engine, said engine being a two cycle engine.

16. A power plant as claimed in claim 6 wherein said internal combustion and said steam engines are rotary-type engines.

17. A power plant as claimed in claim 16 wherein there are two rotary-type internal combustion engines, and one rotary-type steam engine.

18. A power plant as claimed in claim 17 wherein said rotary-type steam engine defines a working chamber having first and second intake ports with said first intake port communicating with an exhaust port of said first rotary-type internal combustion engine and said second intake port communicating with an exhaust port of said second rotary-type internal combustion engine.

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**United States Patent** [19]

DeLuca et al.

[11] **3,995,600**[45] **Dec. 7, 1976**[54] **HYDROGEN FUELED ROTARY ENGINE**

[76] Inventors: **John J. DeLuca**, 2903 Dawson Ave., Silver Spring, Md. 20902; **Wayne E. Hughes**, 356 Mae Road, Glen Burnie, Md. 21061

[22] Filed: **June 9, 1975**[21] Appl. No.: **585,419**

[52] U.S. Cl. .... **123/8.13**; 418/15;  
418/90; 418/100; 418/113

[51] Int. Cl.<sup>2</sup> .... **F02B 53/10**

[58] Field of Search ..... 123/8.13, 8.45, 1 A,  
123/198 D; 418/90, 15, 113, 100

[56] **References Cited****UNITED STATES PATENTS**

1,369,070	2/1921	Williams et al. ....	418/99 X
3,261,334	7/1966	Paschke .....	123/8.45
3,301,233	1/1967	Dotto et al. ....	123/8.45
3,471,274	10/1969	Quigley et al. ....	123/1 A X
3,903,646	9/1975	Norton .....	123/198 D X
3,908,608	9/1975	Fox .....	123/8.45 X

**FOREIGN PATENTS OR APPLICATIONS**

1,345,300	10/1963	France .....	123/8.45
2,115,765	10/1972	Germany .....	123/1 A

Primary Examiner—Carlton R. Croyle

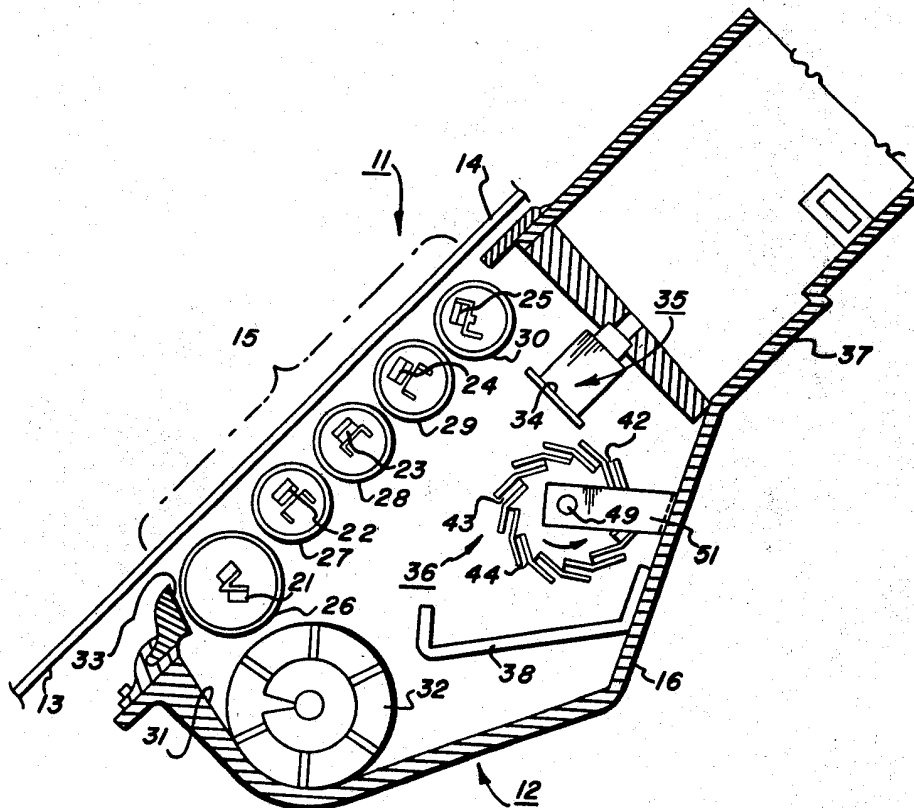
Assistant Examiner—Michael Koczko, Jr.

Attorney, Agent, or Firm—Ronald F. Sandler; Gary F. Grafel; John R. Manning

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**ABSTRACT**

A rotary piston internal-combustion engine adapted to operate on a hydrogen fuel gas mixture injected into the intake chamber of the engine through a plurality of spaced intake ports in the engine housing designed to distribute the flow of the fuel gas mixture evenly along the width of the intake chamber. The exhaust gas outlet of the engine includes a plurality of spaced small exhaust ports so as to decrease the dwell of the apex seal of the rotary piston as it passes over the exhaust gas outlet. The fuel supply system to the engine includes a plurality of mixing chambers to ensure thorough and uniform mixing of the fuel gas mixture, an intake header for distributing the fuel gas mixture to the intake ports, and means for preventing back-fire of the fuel gas mixture in the system. Lubricant may be supplied to the interior of the engine through the fuel intake ports in the form of a lubricating vapor in admixture with the fuel gas mixture. In an alternative embodiment, the engine housing is provided with an inlaid strip of hard porous material designed for passage of lubricating oil.

**10 Claims, 5 Drawing Figures**

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Sheet 1 of 2

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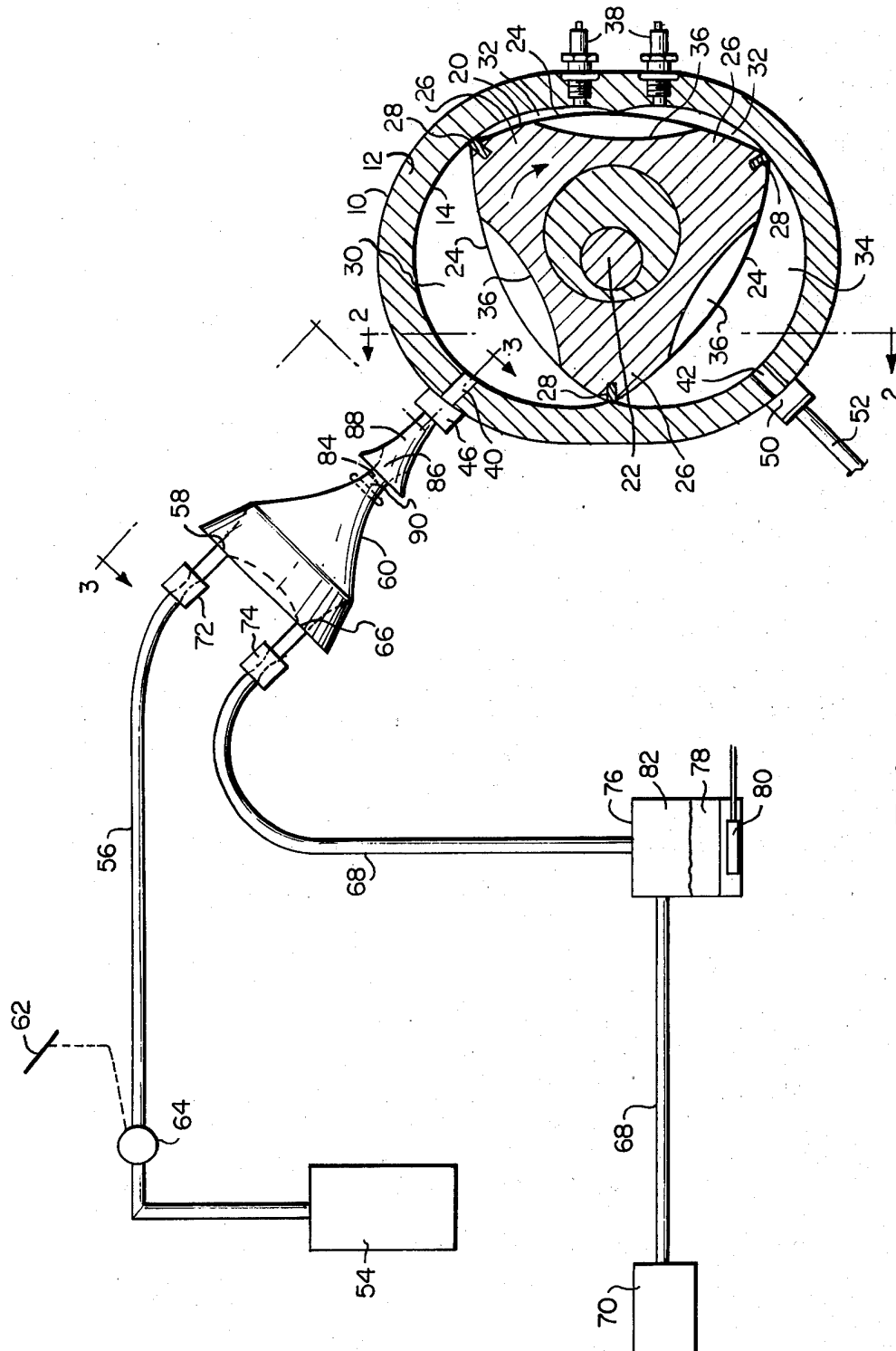


FIG. 1

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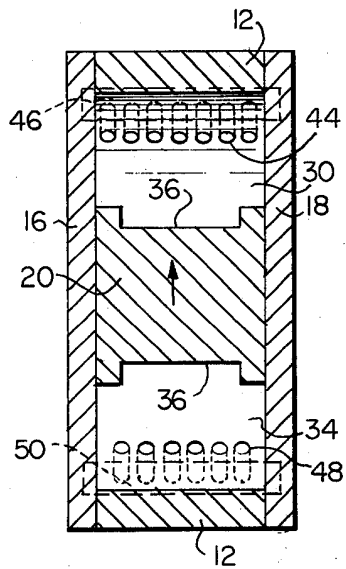


FIG. 2

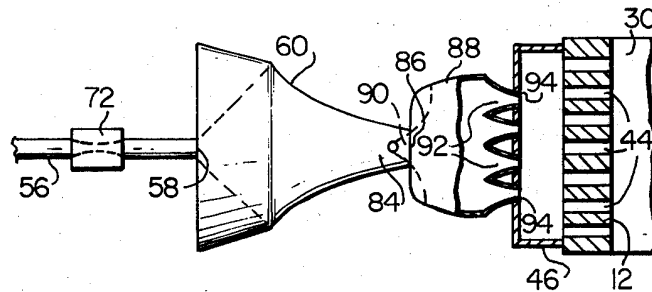


FIG. 3

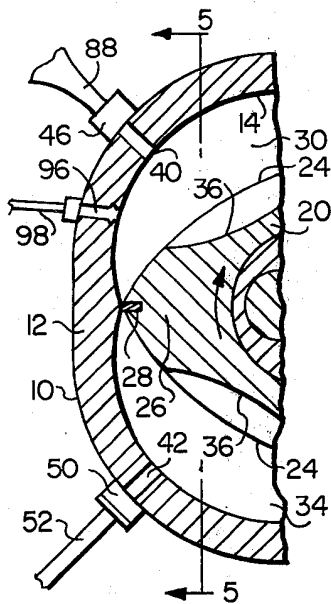


FIG. 4

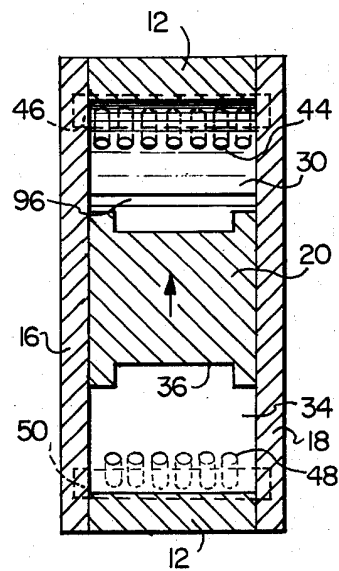


FIG. 5



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## HYDROGEN FUELED ROTARY ENGINE

### ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates generally to rotary piston internal-combustion engines, and more particularly, to such engines adapted to operate on a hydrogen gas fuel mixture.

#### 2. Brief Description of the Prior Art

With the growing demands in recent years of emission control and cost reduction in the automobile industry, there has been an increased interest in the rotary piston engine as a possible replacement for the conventional reciprocating piston engine. In a rotary piston internal-combustion engine, a polygonal piston rotates within an epitrochoidally-shaped engine housing, the piston and housing defining between them a plurality of working chambers that rotate about the axis of the housing and cyclically vary in volume as the piston rotates relative to the housing so as to effectively provide in succession a suction space, a compression space and an expansion space. The previously proposed rotary piston internal-combustion engines have been designed to operate on conventional combustion fuels which are injected generally through a single injection port into the working chambers of the engine where they are admixed with air for ignition. Moreover, in the prior art rotary engines, maintaining adequate lubrication of the piston apex seal surfaces in contact with the housing has been a major problem.

The detrimental air polluting effects of the exhaust gases from conventional combustion fuels are well known. Among the various efforts that have been made to reduce the amount of such air pollutants, it has previously been proposed to fuel internal-combustion engines with hydrogen gas, which burns in air to yield water as the main product of combustion and therefore results in fewer atmospheric contaminants. However, these previous proposals of using hydrogen as a fuel for internal-combustion engines all employed conventional reciprocating piston-type internal-combustion engines and suffered because of the various intake and exhaust valve problems and the extreme difficulties involved in producing a uniform explosion mixture in the firing chamber so as to provide an even ignition and allow the full high energy content of the fuel mixture to be utilized.

### OBJECTS AND SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a rotary piston internal-combustion engine designed to operate in a manner so as to substantially reduce the introduction of pollutants into the atmosphere.

Another object of the present invention is to provide a rotary piston internal-combustion engine designed to operate on a hydrogen fuel gas mixture.

An additional object of the present invention is to provide a hydrogen-fueled rotary piston internal-combustion engine designed to produce a uniform explosion mixture in the firing chambers of the engine.

A further object of the present invention is to provide a hydrogen-fueled rotary piston internal-combustion engine having a fuel injection system designed to distribute the flow of the fuel gas mixture evenly along the width of the intake chamber of the engine so as to provide a smooth and even firing of the fuel gas mixture.

Still another object of the present invention is to provide a hydrogen-fueled rotary piston internal-combustion engine having a fuel supply system designed to prevent backfire of the fuel gas mixture.

Still a further object of the present invention is to provide a hydrogen-fueled rotary piston internal-combustion engine having improved means for maintaining adequate lubrication of the piston apex seal surfaces in contact with the engine housing.

The foregoing and other objects are attained in accordance with one aspect of the present invention through the provision of a novel fuel supply and injection system in a rotary piston internal-combustion engine which enables the engine to operate on a hydrogen fuel gas mixture and thereby substantially reduce the introduction of pollutants into the atmosphere. The fuel inlet passage means extending through the wall of the engine housing into the intake chamber of the engine comprises a plurality of intake ports spaced along a line extending substantially across the width of the engine housing transverse to the direction of rotation of the piston so as to distribute the flow of the fuel gas mixture evenly along the width of the intake chamber. The fuel supply system for delivering a combustible fuel gas mixture from a fuel source to the fuel inlet passage means of the engine includes a plurality of mixing chambers connected in series to ensure thorough and uniform mixing of hydrogen gas with an oxidizing gas, such as air, oxygen, or water vapor, a fuel intake header on the outer surface of the engine housing covering all of the intake ports for distributing the fuel gas mixture from the final mixing chamber to each of the intake ports, and means for preventing backfire of the fuel gas mixture in the system. The exhaust gas outlet passage extending through the wall of the engine housing also comprises a plurality of small exhaust ports spaced along a line extending substantially across the width of the engine housing transverse to the direction of rotation of the piston in order to decrease the dwell of the apex seal of the piston as it passes over the exhaust gas outlet. An exhaust gas header on the outer surface of the engine housing covers all of the exhaust ports and terminates in a single exhaust pipe.

Lubricant for lubricating the apex seal surfaces of the rotary piston in contact with the engine housing, in a preferred embodiment, is supplied to the interior of the engine through the fuel intake ports in the form of a lubricating vapor in admixture with the fuel gas mixture, in which case there is connected to the mixing chambers of the fuel supply system a source of lubricating oil provided with vaporizer means for converting the lubricating oil to lubricating vapor. In an alternative embodiment, the engine housing is provided with an in laid strip of hard porous material leading to the intake chamber of the engine and designed for the passage of lubricating oil.

### BRIEF DESCRIPTION OF THE DRAWINGS

Various objects, features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood from the fol-

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lowing detailed description of the present invention when considered in connection with the accompanying drawings, in which:

FIG. 1 is a central vertical section of a rotary piston internal-combustion engine showing the rotary piston 5 positioned within the engine housing, in combination with an elevational view of a preferred embodiment of the fuel supply and injection system of the present invention;

FIG. 2 is a sectional view taken substantially along the line 2—2 of FIG. 1, looking in the direction of the arrows;

FIG. 3 is a partial top view of the system shown in FIG. 1, taken partly in section substantially along the line 3—3 of FIG. 1, looking in the direction of the 15 arrows;

FIG. 4 is a partial elevational view, taken partly in vertical section, illustrating an alternative embodiment employing a separate lubricating oil inlet means; and

FIG. 5 is a sectional view taken substantially along the lines 5—5 of FIG. 4, looking in the direction of the arrows.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and in particular to FIGS. 1–3, a hydrogen-fueled rotary piston internal-combustion engine in accordance with one embodiment of this invention, is shown as including an engine housing 10 comprising a peripheral wall 12 that has a 30 curved inner surface 14, and a pair of axially-spaced end walls 16 and 18 that are disposed on opposite sides of the peripheral wall 12 and secured thereto. The curved inner surface 14 of the engine housing 10 has basically the form of an epitrochoid in geometric shape 35 and includes two lobe portions.

Within the engine housing 10, the rotary piston internal-combustion engine is of conventional construction and includes a generally triangular rotary piston 20 rotatably mounted in known manner so as to rotate 40 relative to the engine housing 10 and eccentrically with respect to the main engine axis 22. As shown most clearly in FIG. 1, the rotary piston 20 includes three arcuate working faces 24 and three apex portions 26. The apex portions 26 carry radially movable sealing 45 members 28 which are in substantially continuous gas-sealing engagement with the inner surface 14 of the engine housing 10 as the rotary piston 20 rotates within and relative to the engine housing 10. The three working faces 24 of the rotary piston 20 cooperate with the 50 inner surface 14 of the engine housing 10 to effectively define therebetween three separate working chambers separated by the sealing members 28. As the rotary piston 20 rotates relative to the engine housing 10, in the clock-wise direction indicated by the arrow as 55 viewed in FIG. 1, each of these working chambers rotates about the main engine axis 22 and cyclically varies in volume so as to effectively provide in succession a suction space 30, a compression space 32, and an expansion space 34. The working faces 24 of the rotary 60 piston 20 are provided with cut-out portions or channels 36 that permit gases in the combustion space 32 to pass freely from one lobe of the epitrochoidal inner surface 14 to the other lobe when the rotary piston 20 is in the maximum compression position shown in FIG. 65 1.

Sparkplugs 38 are mounted in the peripheral wall 12 of the engine housing 10 adjacent to the compression

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space 32, and at the appropriate time in the engine cycle, the sparkplugs 38 provide ignition for a compressed combustible gas mixture which, on expansion, drives the rotary piston 20 in the direction of the arrow.

The conventional rotary piston internal-combustion engine thus far described is provided, in accordance with the present invention, with novel fuel inlet passage means 40 extending through the peripheral wall 12 of the engine housing 10 into the suction space 30, and novel exhaust gas outlet passage means 42 extending through the peripheral wall 12 of the engine housing 10 from the expansion space 34. As best seen in FIGS. 2 and 3, the fuel inlet passage means 40 comprises a plurality of intake ports 44 spaced along a line extending substantially across the width of the peripheral wall 12 of the engine housing 10 transverse to the direction of rotation of the rotary piston 20. The use of this configuration instead of the one large intake port used in the prior art rotary engines serves the purpose of distributing the flow of the fuel gas mixture evenly along the width of the intake chamber of the engine so as to produce a smooth and even firing of the fuel gas mixture. A hollow fuel intake header 46 extending across the width of the outer surface of the peripheral wall 12 25 of the engine housing 10 covers all of the intake ports 44 for distributing the fuel gas mixture from the fuel supply system to each of the intake ports.

As best seen in FIG. 2, the exhaust gas outlet passage means 42 similarly comprises a plurality of exhaust 30 ports 48 spaced along a line extending substantially across the width of the peripheral wall 12 of the engine housing 10 transverse to the direction of rotation of the rotary piston 20. The use of this configuration instead of the one large exhaust port used in the prior art rotary engines serves the purpose of decreasing the dwell of the sealing members 28 on the apex portions 26 of the rotary piston 20 as they pass over the exhaust gas outlet. An exhaust gas header 50 extending across the width of the outer surface of the peripheral wall 12 40 of the engine housing 10 covers all of the exhaust ports 48 and terminates in a single exhaust pipe 52.

The line of intake ports 44 and the line of exhaust ports 48 are spaced from each other across the line separating the suction space 30 from the expansion space 34 by at least 90°, and preferably as much as 120°, with respect to the main engine axis 22. In the preferred embodiment as shown in FIG. 2, the number of the intake ports 44 and the number of exhaust ports 48 differ by 1, with the spacing of the intake ports and exhaust ports along their respective lines being such that the intake ports and exhaust ports are in staggered relation to each other. If intake ports 44 and exhaust ports 48 were in line and of the same number, sealing members 28 would not wear when they pass over the intake and exhaust port openings. This will effect uneven wear of the sealing members which will cause gaps to form between the sealing members and surface 14 thereby allowing the hydrogen fuel gas mixture and exhaust gases to escape through the gaps. The result would be poor compression and exhaust gas extraction. By staggering the intake and exhaust ports and preferably making the exhaust ports one less than the intake ports, all contact areas of the sealing members will wear evenly for each revolution of the piston, thereby ensuring that all contact areas of the sealing members remain in sliding contact with surface 14. Although the intake ports and exhaust ports are shown as being circular in cross-section, such ports, if desired, can be

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formed in other cross-sectional shapes, such as oblong or rectangular.

The rotary piston internal-combustion engine of the present invention is designed to operate on a combustible fuel gas mixture of hydrogen with an oxidizing gas, such as air or oxygen mixed with water vapor. A uniform combustible hydrogen fuel gas mixture is supplied to the suction space 30 of the engine through the intake ports 44 by means of the fuel supply system illustrated in FIGS. 1 and 3 and which terminates in the fuel intake header 46. The fuel supply system includes a hydrogen storage tank 54 containing hydrogen gas under pressure, and a hydrogen gas conduit 56 connecting the hydrogen storage tank 54 to the hydrogen gas inlet 58 of a first mixing chamber 60. A control pedal or accelerator 62 is operatively linked to a valve 64 in the hydrogen gas conduit 56 to vary the amount of hydrogen fed into the first mixing chamber 60. The first mixing chamber 60 is also provided with an oxidizing gas inlet 66, to which is connected an oxidizing gas conduit 68. In the embodiment shown, with air being used as the oxidizing gas, the other end of the oxidizing gas conduit 68 is connected to an air cleaner 70 through which atmospheric air is drawn into the system. If pure oxygen is to be used as the oxidizing gas, the air cleaner 70 would be replaced with an oxygen storage tank containing oxygen gas under pressure, in which case the oxidizing gas conduit 68 would be provided with suitable valving arrangement to regulate the amount of oxygen fed to the first mixing chamber 60, similar to that described above for the hydrogen gas. Both the hydrogen gas conduit 56 and the oxidizing gas conduit 68 are provided with anti-backfire orifices 72 and 74, respectively, adjacent to their connections with the first mixing chamber 60 for preventing backfire of the combustible fuel gas mixture from reaching the sources of the fuel gases.

Connected into the oxidizing gas conduit 68 is a lubricant supply tank 76 having its lower portion filled with lubricating oil 78 and provided with an electric heater 80 for vaporizing the lubricating oil 78 and thereby converting it to lubricating vapor which fills the upper portion 82 of the tank 76. The oxidizing gas conduit 68 passes through and opens into the upper portion 82 of the tank 76 and thereby carries the lubricating vapor with the oxidizing gas into the first mixing chamber 60.

In the first mixing chamber 60, initial mixing together of the hydrogen gas, the oxidizing gas and the lubricating vapor is effected. The first mixing chamber 60 is provided with a gaseous mixture outlet 84 which is in communication with the gaseous mixture inlet 86 of a second mixing chamber 88 wherein the gases are further mixed so as to ensure a more uniform combustible fuel gas mixture. The gaseous mixture outlet 84 of the first mixing chamber 60 is provided with a one-way valve 90 for preventing backflow of the gaseous mixture from the second mixing chamber 88 to the first mixing chamber 60. As shown in FIG. 3, the second mixing chamber 88 is provided with a plurality of injection nozzles 92 which project into openings 94 in the top of the fuel intake header 46 for injecting the gaseous mixture from the second mixing chamber 88 into the fuel intake header 46, which in turn distributes the gaseous mixture to each of the intake ports 44 extending through the peripheral wall 12 of the engine housing 10 and into the suction space 30 of the engine.

When the gaseous mixture enters the suction space 30 of the engine, the lubricating vapor contained therein condenses on the inner surface 14 of the peripheral wall 12 of the engine housing 10, and thereby effects lubrication on the surfaces of the sealing members 28 in contact with the engine housing as the rotary piston 20 rotates within the engine housing. With the rotation of the rotary piston 20 within the engine housing, the combustible hydrogen fuel gas mixture is successively compressed, ignited by means of the spark-plugs 38, expanded, and finally exhausted through the exhaust ports 48, the exhaust gas header 50 and the exhaust pipe 52.

The above-described fuel supply and injection system in accordance with the present invention is so designed that each succeeding orifice area is larger in cross-section than the preceding orifice area so as to inhibit the building up in the system of any back pressure. This, together with the one-way valve 90 disposed in the gaseous mixture outlet 84 of the first mixing chamber 60 and the anti-backfire orifices 72 and 74 in the hydrogen gas conduit 56 and the oxidizing conduit 68, respectively, ensure operation of the engine without any danger of backfire of the combustible fuel gas mixture reaching the fuel gas sources. Moreover, the two mixing chambers, the fuel intake header and the multiple port fuel inlet passage ensure a thorough and uniform mixing of the fuel gases and an even distribution of the fuel gas mixture along the width of the intake chamber of the engine so as to produce a smooth and even firing of the fuel gas mixture within the engine.

In the embodiment of the present invention in FIGS. 1-3 and described above, lubricant for effecting lubrication of the surfaces of the rotary piston apex sealing members 28 in contact with the engine housing, is supplied to the interior of the engine through the fuel inlet passage 40 in the form of a lubricating vapor in admixture with the fuel gas mixture. In an alternative embodiment of the present invention, illustrated in FIGS. 4 and 5, lubricant is supplied to the interior of the engine in the form of a lubricating oil through a separate lubricating oil inlet passage, in which case the lubricant supply tank 76 could be eliminated from the fuel supply system shown in FIG. 1 so that the oxidizing gas conduit 68 would lead directly from the oxidizing gas source to the first mixing chamber 60.

In the embodiment shown in FIGS. 4 and 5, the engine housing 10 is modified so as to include a lubricating oil inlet passage consisting of an inlaid strip 96 of hard porous material extending through the peripheral wall 12 thereof into the suction space 30 of the engine. As shown in FIG. 5, the inlaid strip 96 extends substantially across the width of the peripheral wall 12 of the engine housing transverse to the direction of rotation of the rotary piston 20. The inlaid strip 96 may be made, for example, of sintered tungsten, tantalum, molybdenum, or any metal or ceramic material that exhibits the proper porosity so as to allow the passage of lubricating oil therethrough and the proper hardness so that its rate of wear is comparable to that of the surrounding housing wall to avoid premature failure of the piston apex sealing members 28 due to uneven surfaces between the inlaid strip and the surrounding housing wall. Lubricating oil from a lubricating oil supply tank, not shown, is supplied to the inlet passage through a lubricating oil conduit 98 and passes through the inlaid strip 96 either by capillary flow or under pressure supplied

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by a suitable pump, not shown, included in the lubricating oil supply system.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A rotary piston internal-combustion engine adapted to operate on a combustible hydrogen fuel gas mixture, comprising: engine housing means; polygonal piston means within said housing means rotatable relative to said housing means and cooperating therewith to effectively define therebetween a plurality of working chambers that rotate about the axis of said housing means and cyclically vary in volume as said piston means rotates relative to said housing means so as to effectively provide in succession a suction space, a compression space and an expansion space; a plurality of apex seal means connected to and circumferentially spaced around the periphery of said piston means and in sliding engagement with said housing means; hydrogen fuel gas mixture inlet passage means extending through the wall of said housing means into said suction space and comprising a plurality of intake ports spaced along a line extending substantially across the width of said housing means transverse to the direction of rotation of said piston means; hydrogen fuel gas mixture supply means for supplying said combustible hydrogen fuel gas mixture from a hydrogen fuel gas mixture source to said hydrogen fuel gas mixture inlet passage means, said hydrogen fuel gas mixture supply means terminating in hydrogen fuel gas mixture intake header means on the outer surface of said housing means covering all of said intake ports for distributing said hydrogen fuel gas mixture to each of said intake ports; exhaust gas outlet passage means extending through the wall of said housing means from said expansion space comprising a plurality of exhaust ports spaced along a line extending substantially across the width of said housing means transverse to the direction of rotation of said piston means and the line of said exhaust ports being staggered in relationship to the line of said intake ports for maintaining even wear on said apex seal means; and means for delivering a lubricating fluid into said working chambers to lubricate said apex seals.

2. The rotary piston internal-combustion engine of claim 1 wherein said exhaust gas outlet passage means further includes exhaust gas header means on the outer surface of said housing means covering all of said exhaust ports and terminating in a single exhaust pipe.

3. The rotary piston internal-combustion engine of claim 2 wherein the line of said intake ports and the line of said exhaust ports are spaced from each other across the line separating said suction space from said expansion spaced by at least 90° with respect to the main axis of the engine and the number of said intake ports and the number of said exhaust ports differ by 1.

4. The rotary piston internal-combustion engine of claim 1, wherein said delivering means includes lubricating oil inlet means extending through the wall of said housing means, into said suction space and comprising an inlaid strip of hard porous material extending substantially across the width of said housing means transverse to the direction of rotation of said piston means,

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and lubricating oil supply means for supplying lubricating oil from a source thereof to said lubricating oil inlet means.

5. The rotary piston internal-combustion engine of claim 1, wherein said delivering means includes lubricating vapor supply means connected to said fuel supply means for effecting of lubricating vapor with said combustible fuel gas mixture for injection into the interior of said housing means through said hydrogen fuel gas mixture inlet passage means, said lubricating vapor supply means comprising a source of lubricating oil and vaporizer means for converting said lubricating oil to lubricating vapor.

6. The rotary piston internal-combustion engine of claim 1 wherein said hydrogen fuel gas mixture supply means includes a first mixing chamber means for effecting initial mixing of the gases composing said combustible hydrogen fuel gas mixture, said first mixing chamber means having a hydrogen gas inlet, an oxidizing gas inlet and a gaseous mixture outlet; hydrogen gas conduit means for supplying hydrogen gas from a source thereof to said hydrogen gas inlet of said first mixing chamber means; oxidizing gas conduit means for supplying an oxidizing gas from a source thereof to said oxidizing gas inlet of said first mixing chamber means; and a second mixing chamber means for effecting further mixing of said hydrogen fuel gas mixture, said second mixing chamber means having a gaseous mixture inlet in communication with said gaseous mixture outlet of said first mixing chamber means and a plurality of injection nozzle means for injecting said hydrogen fuel gas mixture from said second mixing chamber means into said hydrogen fuel gas mixture intake header means.

7. The rotary piston internal-combustion engine of claim 6, further including one-way valve means disposed in said gaseous mixture outlet of said first mixing chamber means for preventing backflow of said gaseous mixture from said second mixing chamber means to said first mixing chamber means.

8. The rotary piston internal-combustion engine of claim 6, further including anti-backfire orifice means both in said hydrogen gas conduit means and in said oxidizing gas conduit means for preventing backfire of said combustible hydrogen fuel gas mixture from reaching said source of hydrogen fuel gases.

9. The rotary piston internal-combustion engine of claim 6, wherein said delivering means includes lubricating vapor supply means in communication with said oxidizing gas conduit means, whereby lubricating vapor is carried with said oxidizing gas to said first mixing chamber means and admixed with said combustible hydrogen fuel gas mixture for injection into the interior of said housing means through said hydrogen fuel inlet passage means, said lubricating vapor supply means comprising a source of lubricating oil and vaporizer means for converting said lubricating oil to lubricating vapor.

10. The rotary piston internal-combustion engine of claim 9, wherein said lubricating vapor supply means comprises a tank having a lower portion filled with lubricating oil and provided with heating means for vaporizing said lubricating oil, and an upper portion containing the vaporized lubricating oil, and said oxidizing gas conduit means passes through and opens into said upper portion of said tank so as to carry said lubricating vapor with said oxidizing gas.

\* \* \* \* \*

**United States Patent** [19][11] **4,030,297****Kantz et al.**[45] **June 21, 1977**

- [54] **HYDROGEN COMPRESSION SYSTEM FOR STIRLING ENGINE POWER CONTROL**
- [75] Inventors: **Don B. Kantz**, Ferndale; **Tim F. Lezotte**, Dearborn, both of Mich.
- [73] Assignee: **Ford Motor Company**, Dearborn, Mich.
- [22] Filed: **June 28, 1976**
- [21] Appl. No.: **700,678**
- [52] U.S. Cl. .... **60/521; 60/522; 60/525**
- [51] Int. Cl.<sup>2</sup> .... **F02G 1/06**
- [58] Field of Search ..... **60/517, 521, 522, 525, 60/526**

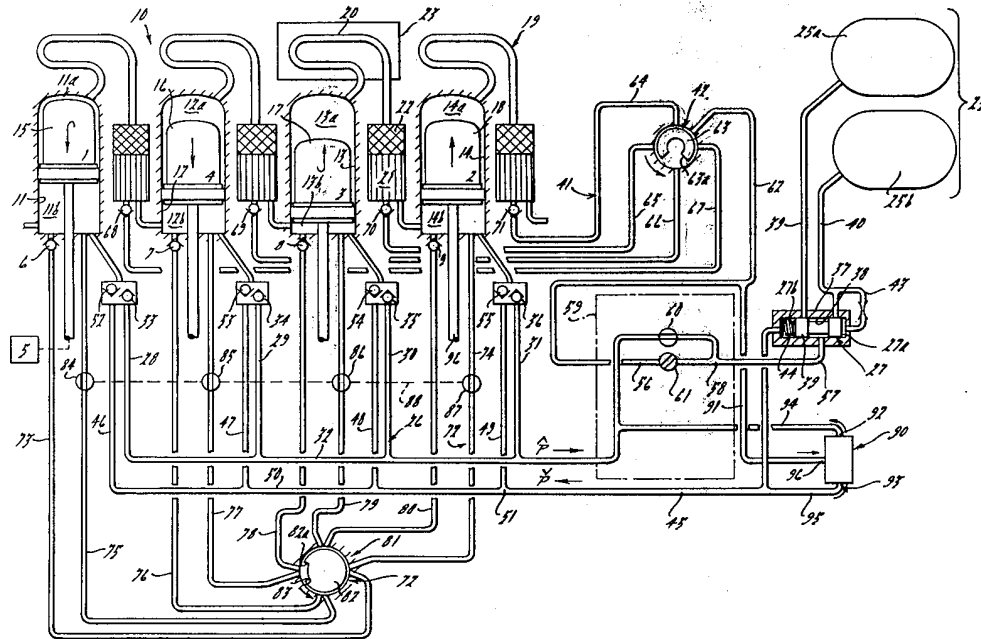
[56] **References Cited****UNITED STATES PATENTS**

2,616,243	11/1952	Van Weenen	60/521
3,699,770	10/1972	Bennethum	60/525 X
3,914,940	10/1975	Bergman	60/521

*Primary Examiner*—Allen M. Ostrager*Assistant Examiner*—Stephen F. Husar*Attorney, Agent, or Firm*—Joseph W. Malleck; Keith L. Zerschling[57] **ABSTRACT**

A closed working fluid system for a regenerative Stir-

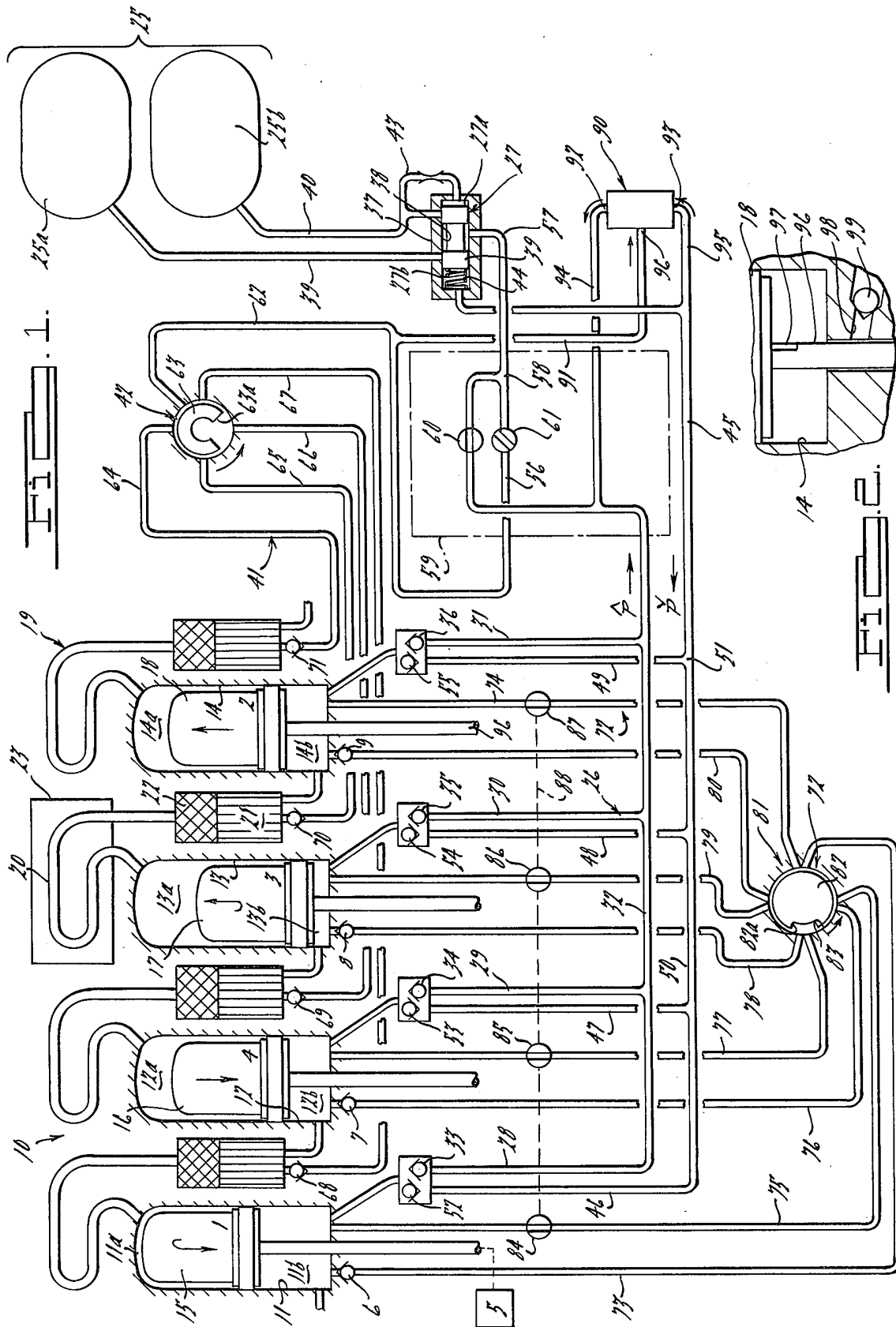
ling engine is disclosed. The system employs double-acting pistons arranged with each low temperature (compression) space connected to one hot (expansion) space of an adjacent piston. The low temperature spaces are all connected to a reservoir system employing two separate chambers, one at a high pressure and another at a relatively low pressure. Control means select the reservoir for communication with the working system depending on the torque demand of the engine; the control means also permits fluid flow to pass from any one low temperature space to the selected reservoir when the pressure condition in the low temperature space exceeds the associated reservoir pressure. Independent communication is provided between each pair of adjacent low temperature spaces; the communication is controlled by a valve operating in phase with the phase changes of the double-acting pistons so that only one pair of low temperature spaces are in communication at any one time. The latter communication operates to displace the independent pumping mechanisms employed by the prior art. The apparatus herein allows the integrated compression spaces to increase the pressure of the working fluid system in series.

**7 Claims, 2 Drawing Figures**

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## HYDROGEN COMPRESSION SYSTEM FOR STIRLING ENGINE POWER CONTROL

### BACKGROUND OF THE INVENTION

Known control methods for controlling the power of a regenerative type Stirling engine do so by changing the mean pressure prevailing in the working chambers of the engine, such engine typically having a hot chamber and a cold chamber per cylinder, these being separated from one another and adapted to be alternately reduced and enlarged in volume by a piston movable in the cylinder. The hot chamber is connected to the cold chamber within the same engine cylinder or to a cold chamber in another cylinder (operating in a phase-displacement manner) by way of a flow path having a regenerator and cooler therein.

To control power, the mean pressure prevailing in the working chambers is so modified that a high pressure is present in the chambers at a high engine torque demand and a low pressure at a low torque demand. These pressure levels, as well as varying intermediate levels, are achieved by means of a compressor driven by the engine and which is effective to pump the working medium into a reservoir. In the case of a power reduction, the reservoir is maintained at a typically high pressure. A compressor for this task has to meet very high standards. It must have a high pressure ratio, must operate without lubrication of the piston and must be sealed to prevent the escape of hydrogen. These requirements can be met only with difficulty, if they are met at all, and only at great expense. Such compressors may be separate units or may be extensions of the piston extending into close-fitting auxiliary cylinders. The piston extensions may be one or more in number and usually extend from the bottom side of the principal piston. In addition to the increased complexity and cost of utilizing a system which is compressor actuated to transfer gases to or from the working chambers to a reservoir, there is the additional problem that pumping of the working medium out of the working chambers by the small compressors takes place relatively slowly.

Separate small compressors have become a popular means of implementing mean pressure control which in turn provides torque control for the engine. Mean pressure control systems of the prior art have emphasized the need for equalizing the mean pressures in the different working chambers, separated by double acting pistons. However, such prior art systems employ injection or ejection of high pressure from one working chamber at a time which creates a temporary inequilibrium lasting for three or four cycles of the engine until mean pressures stabilize again. What is needed is a mean pressure control system which eliminates independent compressors and yet provides a temporary inequilibrium in mean pressures during a torque demand change commensurate with the inequilibrium now experienced by prior art systems.

### SUMMARY OF THE INVENTION

The primary object of this invention is to improve the efficiency and control of a regenerative type Stirling engine by eliminating the necessity for separate and distinct compressor mechanisms capable of transferring working fluid from the working chambers to a reservoir.

Another object of this invention is to rearrange the closed working fluid system of a regenerative type Stir-

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ling engine so that greater weight savings and cost savings can be realized while retaining or improving reliability of the system.

Yet another object of this invention is to provide a regenerative type Stirling engine having a control for the closed working fluid system which achieves greater responsiveness than control systems of the prior art.

Features pursuant to the above objects comprise:

- a. the use of structural means connecting the low temperature chambers, operating as compression spaces, in series so that the pressure of the working fluid of said system may be raised in stages by the phased operation of the engine pistons without the need for an independent compressor mechanism;
- b. the use of structure dividing the pressure reservoir for the working fluid into two parts, one part being maintained at a high predetermined pressure range and the other being maintained at a relatively low operating pressure range, and the use of a shuttle valve selectively communicating the working fluid circuit with one or the other of said reservoirs depending upon the mean pressure within said working circuit whereby the pressure ratio to be overcome by the internal action of said engine is reduced; and
- c. arrangement of the shuttle valve so that the pressure from the reservoir having the highest predetermined pressure is applied against one end of said valve to bias it in one direction and the force of a mechanical biasing spring is applied against the other end of said shuttle valve, the positioning of said shuttle valve being determined by the mean pressure within said working circuit applied to the end of said shuttle valve affected by said biasing spring.

### SUMMARY OF THE DRAWINGS

FIG. 1 is a schematic layout of substantially the entire working fluid system of a regenerative Stirling engine embodying the principles of this invention; and

FIG. 2 is an enlarged sectional view of a portion of piston and cylinder showing an alternative mode for valve 81.

### DETAILED DESCRIPTION

The invention herein is particularly adaptable to a double-acting Stirling cycle hot gas engine of a kind having a plurality of engine cylinders, each receiving a reciprocating piston therein dividing the engine cylinder into an upper chamber containing gas at a high temperature level and a lower chamber containing gas at a low temperature level. Each of the pistons have integrally connected thereto one or more pumping pistons, which during operation of the engine, reciprocate in an axial direction. According to the prior art of Stirling double-acting piston engines, these pumping pistons extend into an adjacent pumping cylinder provided with two check valves to control gas conduits, one gas conduit leading from the lower chamber of the respective engine cylinder to the pump cylinder, and the other gas conduit operating to assist in the alleviation of gases from the pump cylinder. The pumping pistons, working in the pumping cylinder, together with the appertaining conduits and valves, constitute an arrangement whereby it is possible to vary the quantity of working gas employed in the engine in order to vary the power output of the engine.

In an engine of the type described, it is common to connect the conduit leading from the pumping cylinder to a gas storage tank (reservoir) and to include a stop



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valve in said conduit to stop the gas flow as soon as a predetermined pressure is reached in the tank. Each pumping piston will be operating on an enclosed volume of gas behaving as a gas spring. Several disadvantages result from such an arrangement, among which include the drawback that the piston rings, working in the pumping cylinder, will be exposed to severe stresses whenever the engine is operating, even during periods when the pumping pistons are not pumping fluid to the tank. In addition, the cost and weight related to the use of such pumping cylinders and pumping pistons, are undesirable when making an automotive application of such engine.

Turning now to FIG. 1, the closed working fluid system 10 of a regenerative Stirling engine comprises a plurality of cylinders 11, 12, 13 and 14, each divided respectively by reciprocating pistons 15, 16, 17 and 18 into two chambers, spaces or volumes (see 11a, 11b, 12a, 12b, 13a, 13b, 14a and 14b). Chambers 11a, 12a, 13a and 14a may be considered a hot or high temperature chamber for purposes of expansion and the others 11a, 12b, 13b and 14b may be considered a cold or low temperature chamber for purposes of compression. Each of the cold chambers are connected by a first means 19 to an adjacent hot chamber in progressive series. The means 19 includes for each pair of hot and cold chambers a conduit 20, a cooling mechanism 21 for extracting heat from the closed working gas and a regenerator 22 for storing heat units of the gas passing therethrough or for releasing heat units upon fluid movement in the reversed direction. The fluid in the closed working circuit may preferably be hydrogen maintained at a relatively high mean pressure to present excellent thermal conductivity. The fluid in conduits 20 is heated by an external heating circuit 23 surrounding a substantial portion of each of said conduits 20, promoting heat transfer to the gases therein and elevating the gas temperature to about 1300° F. Assembly 5 is a means for deriving work energy from the system 10, such as mechanical swash plate assembly.

Due to the separation of each pair of hot and cold chambers by a piston, both ends of the dividing piston act as a work surface, hence the term double-acting piston arrangement. The pistons are all connected to a common mechanical driven means 24, which assure that the pistons will be operating 90° out of phase with the next most leading or trailing piston.

In automotive applications, the shaft torque of the engine must be varied over a large range during normal operation of the vehicle. Torque control or power control is accomplished by changing the mean cycle pressure of the working gas within the variable volume chambers 11a, 11b, 12a, 12b, 13a, 13b, 14a and 14b. Such pressure variations are usually from a pressure minimum of 25 atmospheres to a pressure maximum of over 200 atmospheres. This invention proposes to connect the compression spaces (cold spaces 11b, 12b, 13b and 14b of adjacent cylinders in a manner which will allow engine compression strokes by way of said pistons 15, 16, 17 and 18 to work consecutively to produce a sufficient pressure head to fill a gas reservoir means 25 used in the pressure regulation of the closed working system 10. The reservoir means 25 contains two separate reservoirs 25a and 25b for additional novel purposes herein; a novel valve 27 responsive to high and low ranges of the mean pressure in the work-

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ing system 10 serves to regulate the pressures in the two reservoirs.

When the closed working system 10 is substantially filled with high pressure gas, leaving the reservoirs substantially depleted and at their low end of a predetermined pressure range, such as may occur at full throttle for the engine, any change of pressure from this condition must involve transfer of gas from the cylinders to the reservoir. To this end, a first means 26 provides a one-way fluid communication to the reservoirs 25. Means 26 comprises conduits 28, 29, 30 and 31 respectively leading from each of the cold chambers and which commonly connect to passage 32; to insure one-way communication from the cold chambers, check-valves 33, 34, 35 and 36 are interposed respectively in conduits 28-31. The passage 32 will be referred to as the Pmax. line, always containing the maximum pressure in the cold chambers except during a transient change of mean pressure during deceleration or acceleration of the vehicle. Pmax. is assured by the orientation of said check valves 33-36 permitting flow only to the reservoirs. Similarly, passage 50 acts as a Pmin. or minimum chamber pressure line, always containing the minimum pressure in the cold chambers as assured by the opposite orientation of one-way valves 52-55 permitting flow only to the cold chambers from the reservoirs by way of a passage or conduit path including 39 or 40, 57, 56, 91 and 95.

Valve 27 directs fluid in passage 32 to one of the two reservoirs 25a or 25b. Valve 27 comprises a valve housing 37 defining a cylindrical bore 38 in which is slidable a closely fitting spool valve 39. Passage 32 by way of passage 57 connects with a center position of the bore 38 and passages 39 and 40 connect with off-center positions of said bore. Passage 39 connects also with the low pressure range reservoir 25a and passage 40 connects with high pressure range reservoir 25b.

One end 27a of spool valve 27 receives a high reservoir pressure force from passage 40 via conduit 43 causing the spool to be biased to the left; the other end 27a is biased to the right by force of a spring 44 and the force of the minimum pressure in the working cylinders via passage 50 and conduit 45. The minimum pressure results from the one-way communication to the cold chambers provided by conduits 46, 47, 48 and 49 commonly connected to passage 50 which in turn connects at 51 to said conduit 45; the one-way check valves 52, 53, 54 and 55 insure fluid flow only into said cylinders causing the pressure in passage 50 to be at about the minimum cycle pressure for the system except during transient changes in mean pressure in the cold chambers.

A second means 41 is employed to direct fluid from the reservoirs and inject said fluid into one cylinder at any one moment by a timed valve 42 for purposes of increasing the mean working pressure in response to a demand for more engine torque. Means 41 comprises conduit 56 which connects also to passage 57 at 58. A gate valve assembly 59, responsive to a change in engine torque demand, directs fluid to flow through first means 26 or through second means 41. The assembly has a gate valve 60 interrupting passage 32 and a gate valve 61 interrupting conduit 56. Fluid flow permitted through conduit 56 is carried by passage 62 to the timed valve 42. Timing of the injection of reservoir fluid into any one cylinder is important to reduce or eliminate negative work on the added fluid by the associated piston. To this end the injection is timed to occur



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at the end of the compression cycle and substantially during the expansion cycle. Obviously this requires a control to orchestrate this type of injection among the several cylinders each operating at a different phase from the other.

The timing of injection of reservoir pressure into only one cylinder at any one moment is modified in one respect. It has been found that the disadvantage of negative work, which would occur if all cold chambers were injected simultaneously is outweighed by the disadvantage of slow engine response when the mean pressure reaches a certain level. Thus, a switch-over valve assembly 90 is employed to permit injection simultaneously into all of the cold chambers by a path through conduits 39 or 40, 57, 56, 91, 95, 45, 50 and each of 46, 47, 48 and 49 when the mean pressure is sensed to be above a middle level. During the initial stage of acceleration, the mean pressure will be below the middle level and valve 90 will be in the other position blocking communication to 95, but permitting communication to 94 which in turn is blocked by one-way valves 33-36 from entering the cold chambers.

Timed valve 42 has a valve element 63 which causes to rotate at a speed synchronous with phase changes in the cylinders 11-14, whereby fluid communication between passage 62 and one of the passages 64, 65, 66 or 67 is permitted through opening 63a at the precise moment when injection of higher pressure fluid is best to effect a desired torque change. One-way check valves 68, 69, 70 and 71 insure injection of fluid into the cylinders.

A third means 72 interconnects the cold spaces in a most important manner. Means 72 comprises pairs of conduits 73-74, 75-76, 77-78, and 79-80, each pair of conduits connect separately to the interior cylinder 83 of a timed valve 81. The timed valve has a rotor valve member 82 which rotates in synchronous phase with the phase changes of the cylinders 11-14 so that a communication through valve opening 82a and through any one pair of passages is permitted at the precise time when one of the cold chambers associated with the pair of passages is undergoing compression or has completed compression. The latter is preferable to provide the greatest opportunity for a particular cold space to transfer fluid to the reservoir means before a communication is established to allow transfer to the next trailing cold chamber. Complete cut-off of the communication between cold chambers can be established by the sizing of the opening 82a; however, as a practical matter, the check valves 6, 7, 8 and 9 will function to limit the communication.

Thus, the cold spaces are connected in sequential series so that the pistons 15-18 may perform one or more phase pumping functions to increase pressure beyond the maximum cycle pressure. The increased pressure is permitted to flow back to the reservoirs for restoring pressure therein. The third means 72 is made to operate in conjunction with the opening of passage 32 by actuating gate valves 84, 85, 86 and 87 and gate valve 60 through a linkage 88 to open and close simultaneously.

When the demand for engine shaft torque is reduced, indicated by a reduced throttle opening or position, the mean cycle pressure (P mean) must be reduced by transferring fluid (hydrogen) from the engine to the reservoir means. Gate valve 60 is opened and gate valve 61 is closed. During a portion of a cycle at some operating condition where the maximum cycle pressure

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(P max.) is greater than the reservoir pressure ( $P_r$ ), fluid will flow through one of the check valves 33-36 and gate valve 60, directly to the reservoirs 25. When P max. is less than  $P_r$ , fluid cannot flow from the reservoirs to the cold chambers through passage 32 (P max.) because of the check valves 33-36; fluid will flow into the adjacent trailing compression space during or at the end of the associated compression stroke of the cold space from which fluid is flowing. The latter is permitted for each cold space in series timing as controlled by valve 81. Such transferred fluid will then be further compressed to an even higher pressure head and allowed to flow to the reservoir system when P max. is instantaneously greater than  $P_r$ , in any subsequent cold chamber, or again to the next adjacent trailing compression space.

The timed valve 81 may be constructed as shown with a valve seat arranged as circular interior cylinder having openings equi-circumferentially arranged thereabout. Each set of adjacent openings are fluidly connected to adjacent compression spaces, said sets being arranged in an order according to the series connections of cylinders. The central rotor valve rotates within the cylinder at a speed so that a valve or opening 82a (having a dimension effective to span two adjacent passage openings) will connect a set of openings substantially during the compression phase of one of the associated cold spaces. Actuation of rotor valve 82 can be by mechanical drive train or by hydraulic means pulsing said member in phase with the pressure variations of the cold spaces.

A simpler mode of making the valve 81 may be use of a groove 97 in the upper end of each piston rod 96 (see FIG. 2). When the piston rod substantially reaches bottom dead center at or near the completion of the compression stroke, a communication through groove 97 and passage 98 is established. Passage 98 (and one-way valve 99) act as any of the passages 73, 76, 78, 80 with a respective check-valve 6, 7, 8 or 9. Passage 98 leads to the next trailing cold chamber. Phase timing is achieved by the action of the piston rod.

The reservoir system 25 stores all of the hydrogen gas or fluid required to raise the engine mean cycle pressure from the minimum level of about 25 atmospheres to a maximum in excess of 200 atmospheres. The pressure will range from slightly above P min. (that pressure which exists in an expanded cold space) to the highest engine operating pressure, depending upon the reservoir system volume. With a simple reservoir system according to the prior art employing a single bottle, the  $H_2$  would, in the most difficult situation, have to be compressed 200 atmospheres resulting in the imposition of extremely high forces on anyone pumping piston. To overcome this, a dual reservoir system is employed. This reservoir system has a shuttle or spool valve assembly 27 which distributes pressure to one of two reservoirs 25a and 25b. Reservoir 25b is utilized for the high pressure range of the engine when the engine mean cycle pressure is high. Reservoir 25a is used for the low pressure range, when the mean cycle pressure is low. This reduces the maximum operating pressure ratio (imposed on the integral series pumping system) during compression and also reduces the work of compression. The balance of such forces on opposite ends of the spool valve determines the position of the spool valve to communicate passage 57 with either passage 39 for reservoir 25a or passage 40 for reservoir 25b.

We claim:

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1. For use in a regenerative Stirling engine employing a plurality of double-acting pistons, each operating within a cylinder to define therein hot and cold chambers on opposed sides of each of said pistons, an apparatus for controlling the power of said engine, comprising:

- a. reservoir means regulated to maintain a predetermined pressure therein and being connected to said closed pressurized gas system,
- b. first means providing a reversible fluid communication for each one of said cold chambers and one of the next most adjacent hot chambers in series,
- c. second means providing a one-way fluid communication between each of said cold chambers and said reservoir means, said communication permitting pressurized fluid flow from said cold chambers to said reservoir during steady state or reduced engine torque demand and when the pressure in any one of said cold chambers exceeds the pressure in said reservoir means,
- d. third means providing a one-way fluid communication between said reservoir means and said cold chambers, said communication permitting pressurized fluid flow sequentially from said reservoir means to each one of said cold chambers during increased engine torque demand and when the pressure in said reservoir means exceeds the pressure in any one of said cold chambers, and
- e. fourth means providing a one-way fluid communication between adjacent cold chambers, said communication being timed in phase relation to the operation of said piston so that the communication is permitted when the egressing cold chamber is undergoing or has completed compression and the ingressing cold chamber is preparing to undergo compression whereby fluid in said cold chambers is subjected to a staged pumping effect for increasing the mean pressure therein.

2. For use in a regenerative Stirling engine employing an assembly having a plurality of double-acting pistons, each operating within a cylinder to define therein hot and cold chambers on opposed sides of each of said pistons, an apparatus for controlling the power of said engine, comprising:

- a. reservoir means regulated to maintain a predetermined pressure therein and being connected to said closed pressurized gas system,
- b. first means providing a one-way fluid communication between each of said cold chambers and said reservoir means, said communication permitting pressurized fluid flow from said cold chambers to said reservoir when the pressure in said cold chambers exceeds the pressure in said reservoir,
- c. second means providing a one-way fluid communication between said cold chambers in series, the direction of said one-way communication being from one cold chamber undergoing compression to the next cold chamber lagging in compression,
- d. a power control responsive to the torque demand of said engine to open said first means communicating said cold chambers with said reservoir for reducing the pressure in said system and to open said second means to permit said fluid pressure to flow between cold chambers in series in accordance with the thermodynamic cycling of said piston and cylinder assembly, thus employing said pistons as a stepped pumping system for restoring an elevated pressure in said reservoir means.

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3. The apparatus as in claim 1, in which said reservoir means is comprised of two independent reservoir chambers, each chamber being independently controlled to separate pressure levels, one being regulated to a relatively high pressure level and the other regulated to a relatively low pressure, said reservoir means further including a directional valve effective to selectively connect one of said reservoirs with the closed fluid system in response to the engine torque demand requiring either an associated low pressure or an associated high pressure in said system, whereby the work required of said double-acting pistons for said staged pumping effect is reduced.

4. The apparatus as in claim 2, in which said reservoir means is comprised of two independent reservoir chambers, each chamber being independently controlled to separate pressure levels, one being regulated to a relatively high pressure level and the other regulated to a relatively low pressure, said reservoir means further including a directional valve effective to selectively connect one of said reservoirs with the closed fluid system in response to the engine torque demand requiring either an associated low pressure or an associated high pressure in said system, whereby the work required of said double-acting pistons for said staged pumping effect is reduced.

5. The apparatus as in claim 1, in which said reservoir means particularly comprises a pair of reservoir chambers, and a shuttle valve to alternately permit communication between one or the other of said reservoirs with the closed fluid system, one of said reservoir chambers being regulated to a high pressure level equal to or in excess of 150 atmospheres and having a passage communicating said reservoir with one end of said shuttle valve to bias said valve in one direction, the other of said reservoir chambers being regulated to a relatively low pressure condition in the range of 70-150 atmospheres, resilient means biasing said valve in an opposite direction, and means communicating fluid mean pressure within said system with said valve to add to the force of said resilient means operating in said opposite direction, said shuttle valve being moved to one position or another by the balance of forces imposed on said valve thereby providing communication with one or the other of said reservoirs.

6. The apparatus as in claim 2, in which said power control means has a gating valve comprised of an extension of said piston having one or more grooves defined thereon to act as a valve, said piston extension being movable within a close fitting cylindrical space defined by a wall acting as a valve housing, said communicating means between said cold chambers being connected to a predetermined location of the wall of said cylindrical space whereby upon movement of said piston, said groove is caused to traverse said communicating means permitting a timed completion of fluid communication in response to a predetermined compression position of said piston.

7. A regenerative Stirling cycle engine system, comprising:

- a. means defining a hot gas volume containing a gas having a low or high density and respectively a high or low thermal conductivity,
- b. means defining a low temperature gas volume in communication with said hot gas volume, each low temperature gas volume being associated with one hot gas volume to define a pair of cycling volumes,

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- c. piston means associated with each pair of cycling volumes and being in communication with at least the low temperature gas volume for varying the low temperature volume in timed relation to the variations in the hot gas volume, 5
- d. thermal regenerator and cooling means intercoupling the hot gas volume and the low temperature gas volume of each pair of cycling volumes to provide reversible thermodynamic gas flow therebetween during changes of volume, 10
- e. means coupled to said means defining a hot gas volume for releasing thermal energy thereinto,
- f. means coupled to said piston means for deriving 15 working energy from the system,

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- g. means providing a one-way fluid connection between adjacent low temperature volumes in series, h. means fluidly connecting said pair of volumes, and i. control means selectively permitting fluid communication through any two selected and adjacent low temperature volumes of means (g), one of said low temperature volumes undergoing compression or is at a compressed condition, while allowing continuous one-way fluid communication from said selected and adjacent low temperature volumes to a reservoir so that if the instantaneous pressure of said reservoir is greater than said communicated low temperature volume, one low temperature space will pump fluid into the other lower temperature space to be raised in pressure therein.

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**United States Patent** [19][11] **4,031,865****Dufour**[45] **June 28, 1977****[54] HYDROGEN-OXYGEN FUEL CELL FOR USE WITH INTERNAL COMBUSTION ENGINES****[76] Inventor: Patrick Dufour, 14 Hawthorne St., Laconia, N.H. 03246****[22] Filed: Oct. 1, 1975****[21] Appl. No.: 618,442****[52] U.S. Cl. .... 123/1 A; 123/3; 123/DIG. 12****[51] Int. Cl.<sup>2</sup> ..... F02B 43/08****[58] Field of Search .... 123/1 A, 3, 119 E, DIG. 12; 204/129****[56] References Cited****UNITED STATES PATENTS**

1,262,034	4/1918	Frazer .....	123/DIG. 12
1,876,879	9/1932	Drabold .....	123/DIG. 12
2,140,254	12/1938	Zavka .....	123/3 X
2,742,886	4/1956	McPherson .....	123/3 X
3,458,412	7/1969	Shinagawa et al. ....	204/129
3,648,668	3/1972	Pacheco .....	123/1 A X

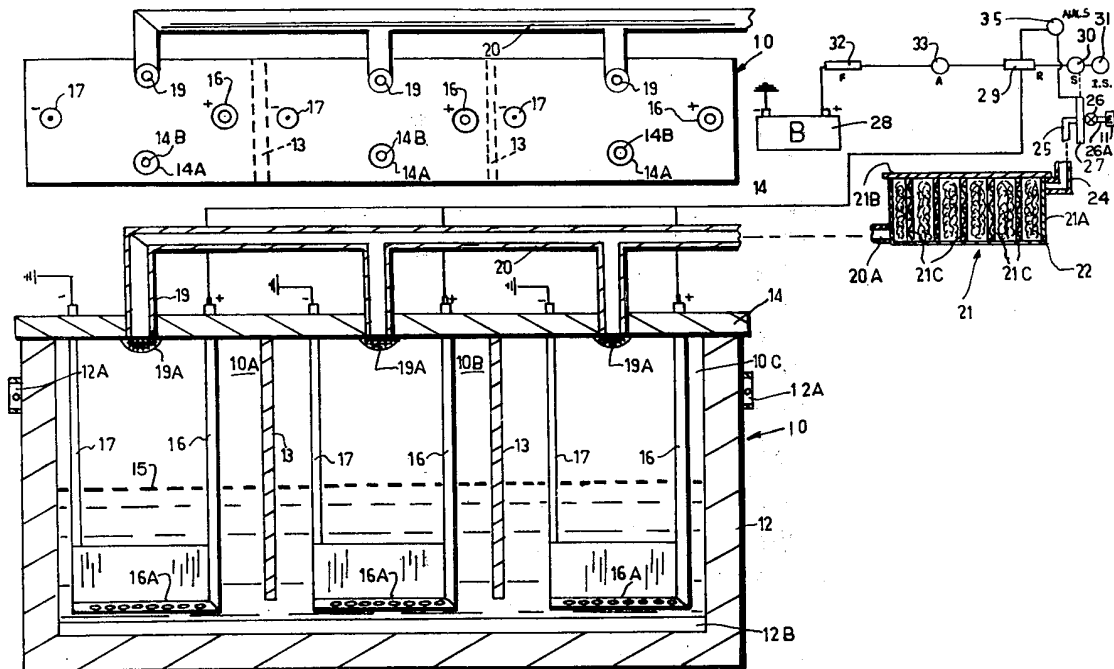
3,939,806 2/1976 Bradley ..... 123/DIG. 12

**FOREIGN PATENTS OR APPLICATIONS**

221,887 6/1942 Sweden ..... 123/3

*Primary Examiner—C. J. Husar**Assistant Examiner—Craig R. Feinberg***[57] ABSTRACT**

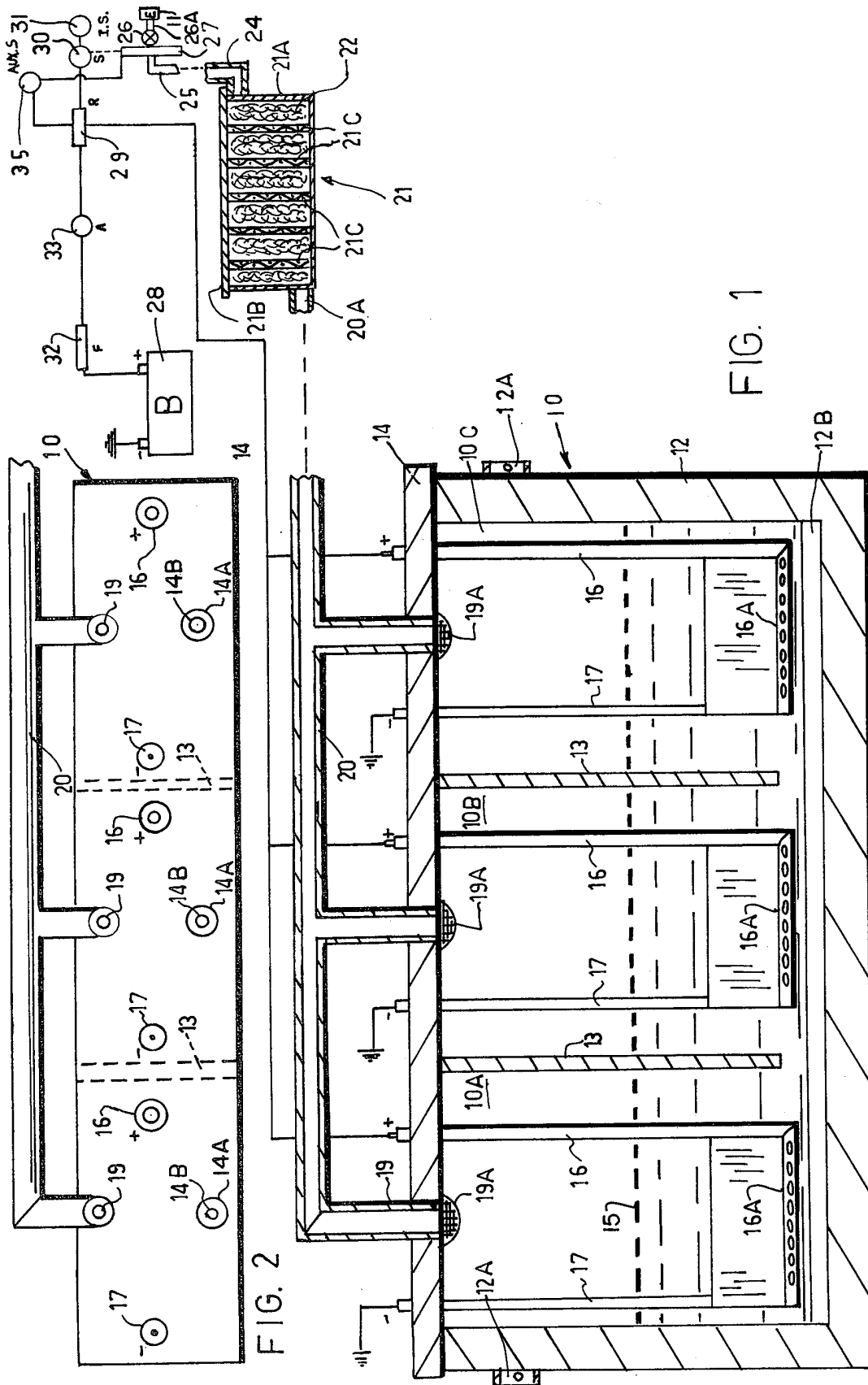
A fuel cell for generating a hydrogen and oxygen gas utilizing a water electrolyte and a catalyst selected from the group consisting of sodium hydroxide and potassium carbonate. The fuel cell includes a pair of electrodes connected in circuit with an electrical power supply and an outlet for directing the generated hydrogen and oxygen to a drier where it is dried and mixed to form a combustible fuel mixture. The fuel mixture is then directed in accordance to engine demand to the intake manifold of an internal combustion engine as a fuel supplement.

**1 Claim, 1 Drawing Figure**

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## HYDROGEN-OXYGEN FUEL CELL FOR USE WITH INTERNAL COMBUSTION ENGINES

### PROBLEM AND PRIOR ART

Heretofore, numerous efforts have been made to increase the mileage attainable from a gallon of gasoline, when such is used as a fuel for an internal combustion engine, e.g., in an automobile. The prior known effects comprised of utilizing various types of additives to the fuel prior to burning. Other efforts comprised of employing various devices for improving ignition and/or timing of the engine so as to achieve maximum efficiency. Other efforts have comprised of utilizing alternate or supplemental fuel. While various efforts have been disclosed in various publications for utilizing hydrogen gas as a fuel for internal combustion engines, it is not known whether any of such efforts have in fact been reduced to actual practice by others.

### OBJECTS

It is an object of this invention to provide a method and apparatus whereby hydrogen and oxygen can be generated by electrolysis from water containing a catalyst and whereby the generated gases can be mixed to form a combustible fuel mixture for use as a supplemental fuel in operating an internal combustion engine.

Another object is to provide a fuel cell for generating hydrogen and oxygen for use as a fuel for operating an internal combustion engine.

Another object is to provide a hydrogen generator or fuel cell wherein the amount of gases generated is proportional to engine demand.

### BRIEF SUMMARY OF INVENTION

The foregoing objects and other features and advantages of the invention as attained by generating by electrolysis of water a hydrogen and oxygen gas which are mixed to form a combustible mixture which is then fed to the intake manifold of an internal combustion engine which is operating on conventional fuels, in accordance with engine demand. This is attained by a hydrogen generator having one or more fuel cells. Each fuel cell includes a pair of electrodes extending into a water electrolyte having a catalyst, e.g., sodium hydroxide, dispersed therein. When utilized in a vehicle, the electrodes of the fuel cell are connected in circuit to the power supply of the vehicle. The generated gases are directed from the fuel cell to a dryer where the gases are dried and mixed to form a combustible fuel mixture. The fuel mixture is thereafter directed to the intake manifold of an internal combustion engine as a fuel supplement.

### IN THE DRAWINGS

FIG. 1 illustrates a fuel cell embodying the present invention and schematically shown as utilized in a vehicle.

FIG. 2 is a plan view of the fuel cell of FIG. 1.

### DETAILED DESCRIPTION

This invention is directed to a method of generating and supplying hydrogen gas as a fuel supplement to an internal combustion engine, and an improved hydrogen generator or fuel cell for generating the hydrogen gas. By supplementing the burning of a conventional fuel with hydrogen, the internal combustion engine in operation is capable of producing more work. The method

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comprises of generating, by electrolysis of water, a hydrogen and oxygen gas. To enhance the electrolysis, a catalyst, e.g., sodium hydroxide or potassium carbonate is added to the water electrolyte. The hydrogen and oxygen so produced is dried and mixed to form a fuel mixture which is then fed to the intake manifold of an internal combustion engine. The rate of generation of the hydrogen and oxygen gas is controlled in accordance with engine demand.

Referring to the drawings, there is shown the improved hydrogen generator 10 for generating hydrogen and oxygen gas for use in a vehicle powered by an internal combustion engine 11, e.g., a gasoline engine, diesel or the like. It will be understood that the engine 11 comprises a conventional internal combustion engine utilizing ordinary gasoline as an operating fuel if it be a gas engine, or diesel oil if it is an diesel.

As shown, the hydrogen generator or fuel cell 10 includes a housing 12 having one or more partitions 13 to define a multi-chamber fuel cell 10. It will be understood that the fuel cell 10 may be constructed to have one or more cell chambers. The illustrated hydrogen generator or fuel cell 10 is thus shown as having three fuel cell chambers 10A, 10B, and 10C. The upper end of the fuel cell housing 12 is closed for a cover or closure 14. Mounting plates 12A are connected to the housing 12 for providing a means for clamping the hydrogen generator 10 to the frame structure of a vehicle.

Formed in the cover 14 to communicate with the respective chambers 10A, 10B and 10C is an inlet 14A closed by a filler cap 14B through which the respective chambers can be charged with an electrolyte. The filler cap 14B has a valve in it to compensate for any excess vacuum which is created when the engine is running.

In accordance with this invention the electrolyte comprises water 15. A catalyst is dispersed in the water 15. The catalyst comprises sodium hydroxide or potassium carbonate.

As shown in FIG. 1, the partitions 13 are spaced from the bottom of the housing so that the respective chambers 10A, 10B, 10C are in communication with one another. Also the bottom of the housing 12 is formed with ribs 12B running longitudinally of the housing 10. The ribs 12B thus enhance the flow of electrolyte from one chamber to the other. The arrangement is such that sediment chambers are formed at the bottom of the housing 12.

Extending into the electrolyte reservoir of the respective cell chambers 10A, 10B, 10C are a positive and negative electrode 16 and 17 respectively. The arrangement is such that when the electrodes are energized, the hydrogen and oxygen in its respective gaseous form is liberated. The positive electrode is also defined as an air tube which is perforated along the lower end 16A whereby the air causes agitation sufficient to stir or liberate the hydrogen forming at the electrode.

Extending through the cover 14 over each of the cell chambers 10A, 10B and 10C is a gas outlet 19 which connects with conduit 20 whereby the oxygen and hydrogen gases generated are directed to a dryer 21. A screen 19A is extended across the inlet 19 to prohibit foreign matter from entering conduit 20. As shown, the dryer 21 comprises a housing 21A and a cover 21B. Disposed in the housing of the dryer are a series of spaced copper screens 21C and a filter insert 22 is disposed between the screen 21C within the dryer to

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effect a drying of the generated gases. Such filtering inserts may comprise steel wood, fiber glass, asbestos fiber, mica chips and the like.

In passing through the dryer, the moisture contained in the gases generated is separated therefrom. As shown in FIG. 1 the dryer is a separate unit connected by a conduit or hose 20A to the outlet 20 of the hydrogen generator 10 and it is located at a higher elevation relative to fuel cell 10.

The outlet 24 of dryer 21 connects by a conduit 25 to the inlet end of a control valve 26. The outlet 26A of the valve is connected to the intake manifold of the engine 11.

An actuator 27, e.g., an accelerator of a vehicle is operatively connected to the control valve 26 so that the latter is rendered responsive to the movement of the accelerator 27. The arrangement is such that the amount of gases introduced to the intake manifold of the engine is rendered proportional to engine demand or speed.

As best seen in FIG. 1, the negative electrode 17 as is the negative electrode of a battery 28 is grounded. The electrical circuit includes a relay 29 which when actuated controls a rheostat switch 30 to control the rate at which the gases are generated in the fuel cell 10. As seen in FIG. 1, the accelerator is connected to the rheostat switch 30 by a linkage so that as the engine speeds up and requires more fuel, more gases will be generated. The relay 29 in turn is also wired in circuit to an ignition switch 31. The usual fuse 32 and ammeter 33 is wired in circuit with the relay 29. An auxiliary switch with 35 light is in circuit between the accelerator 27 and the relay.

In operation, it will be noted that when the ignition switch 31 is closed the engine 11 can be started in the conventional manner. That is, gasoline is fed to a carburetor where it is mixed with air and the gas mixture fed to the respective cylinders where it is fired. With the fuel cell 10 connected in circuit as seen in FIG. 1, the actuation of the accelerator causes the fuel cell to generate hydrogen and oxygen gases which are then passed to a dryer 21 and then to the control valve 26 to the intake manifold of the engine. The hydrogen thus fed to the cylinder of the engine mixes with the conventional fuel thereby enhancing the energy level of the

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fuel by the amount of energy contained in the hydrogen gases. With the hydrogen supplement it has been discovered that the miles attainable by an automobile engine per gallon of gas is considerably enhanced.

While the invention has been described with reference to an automobile engine, the principle can be applied to a stationary engine, diesel engine and in general to any type of internal combustion engine, and irrespective of the fuel customary for operating such engine.

As the invention has been described with respect to a particular embodiment and method, it will be understood and appreciated that variations and modifications may be made without departing from the spirit or scope of the invention.

What is claimed is:

1. In combination, an internal combustion engine having an intake manifold, and a carburetor for supplying a fuel-air mixture to said engine, a hydrogen and oxygen gas generator for supplying a hydrogen gas fuel supplement to said engine, said gas generator comprising a cell containing water, a negative and positive electrode extending into said water, a catalyst of an alkaline base dispersed in said water, an electrical D.C. power supply connected in circuit with said electrodes whereby hydrogen gas is generated when said electrodes are energized, a rheostat switch in circuit with said power supply to control the rate of said hydrogen gas generator, a dryer, conduit means connecting the gases generated in said cell to said dryer, means for directing the gases dried in said dryer to said intake manifold, and accelerator means operatively connected to said rheostat switch for controlling the rate of gas generation in accordance to engine demand, and wherein said positive electrode is perforated to permit the introduction of air into said cell to enhance liberation of the hydrogen gas forming at the negative electrode.

\* \* \* \* \*

**United States Patent** [19][11] **4,033,133****Houseman et al.**[45] **July 5, 1977**

- [54] **START UP SYSTEM FOR HYDROGEN GENERATOR USED WITH AN INTERNAL COMBUSTION ENGINE**
- [75] Inventors: **John Houseman, Pasadena; Donald J. Cerini, Flintridge, both of Calif.**
- [73] Assignee: **California Institute of Technology, Pasadena, Calif.**
- [22] Filed: **Mar. 22, 1976**
- [21] Appl. No.: **668,783**
- [52] U.S. Cl. .... **60/606; 23/288 R; 48/61; 48/102 A; 48/103; 48/107; 48/117; 48/DIG. 8; 60/300; 123/3; 123/179 R; 123/DIG. 12; 423/650**
- [51] Int. Cl.<sup>2</sup> ..... **F02B 33/44**
- [58] Field of Search ..... **48/61, 116, 117, 102-103, 48/107, DIG. 8, 197 R, 199 R, 212, 213; 123/3, 1 A, 179 R, DIG. 12; 60/300, 606; 23/281, 288 R; 252/373; 431/DIG. 68; 423/650**

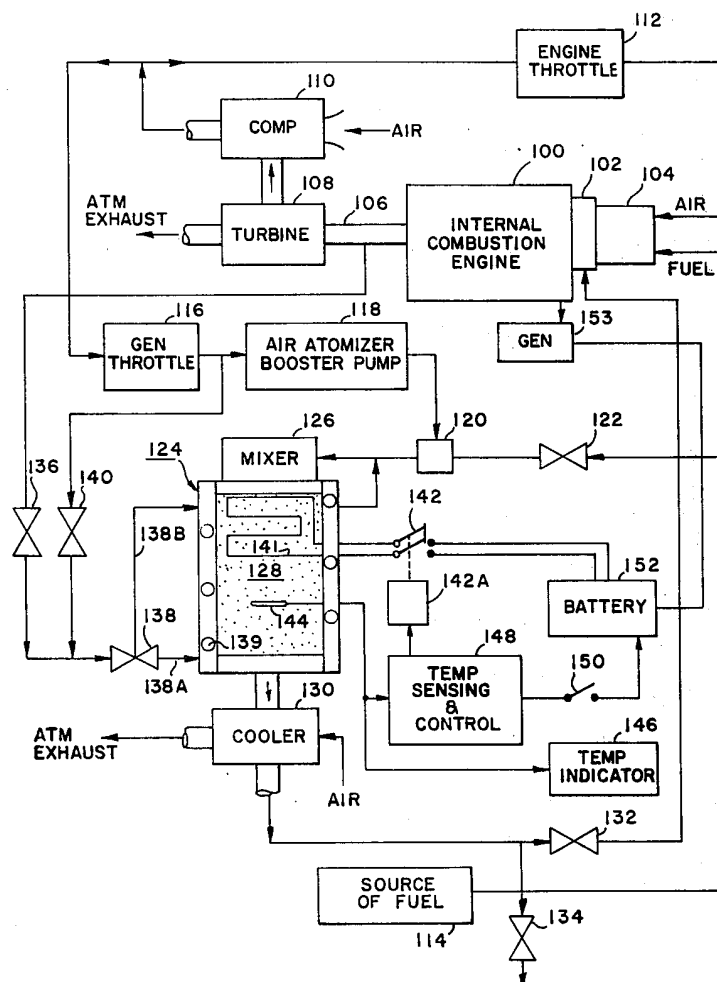
[56] **References Cited****UNITED STATES PATENTS**

- 2,803,295 8/1957 Ambrose et al. .... 48/103
- 2,897,073 7/1959 Shipp ..... 48/103

- 3,635,200 1/1972 Rundell et al. .... 123/3
- 3,717,129 2/1973 Fox ..... 123/1 A
- 3,732,690 5/1973 Meijer ..... 123/1 A
- 3,908,606 9/1975 Toyota et al. .... 123/3
- 3,911,675 10/1975 Mondt ..... 60/300
- 3,954,423 5/1976 Hamper et al. .... 48/107
- 3,982,910 9/1976 Houseman et al. .... 48/61

*Primary Examiner—Robert L. Lindsay, Jr.**Assistant Examiner—George C. Yeung**Attorney, Agent, or Firm—Frielich, Lindenberg*[57] **ABSTRACT**

A hydrogen generator provides hydrogen rich product gases which are mixed with the fuel being supplied to an internal combustion engine for the purpose of enabling a very lean mixture of that fuel to be used, whereby nitrous oxides emitted by the engine are minimized. The hydrogen generator contains a catalyst which must be heated to a pre-determined temperature before it can react properly. To simplify the process of heating up the catalyst at start-up time, either some of the energy produced by the engine such as engine exhaust gas, or electrical energy produced by the engine, or the engine exhaust gas may be used to heat up air which is then used to heat the catalyst.

**9 Claims, 6 Drawing Figures**



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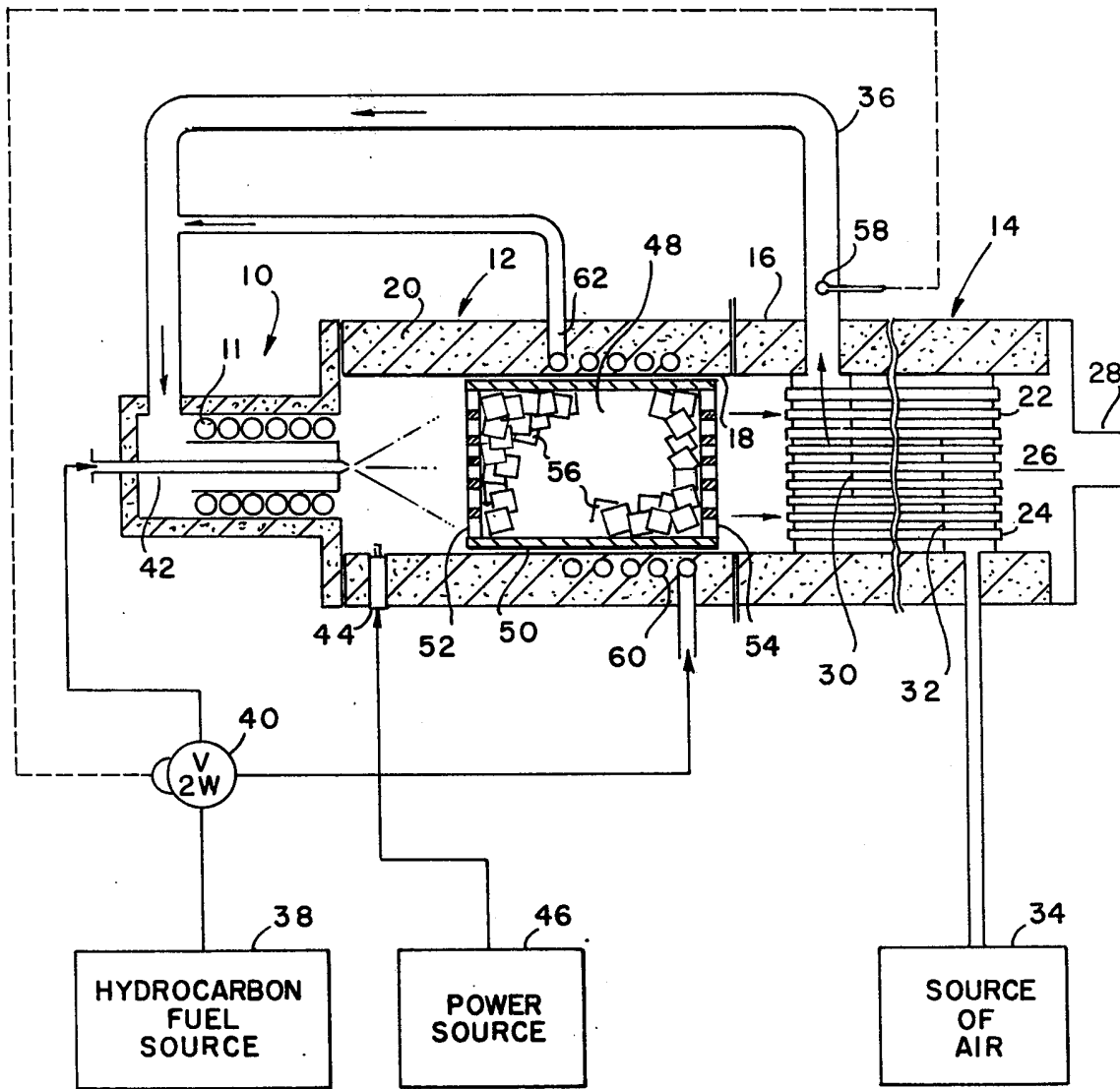
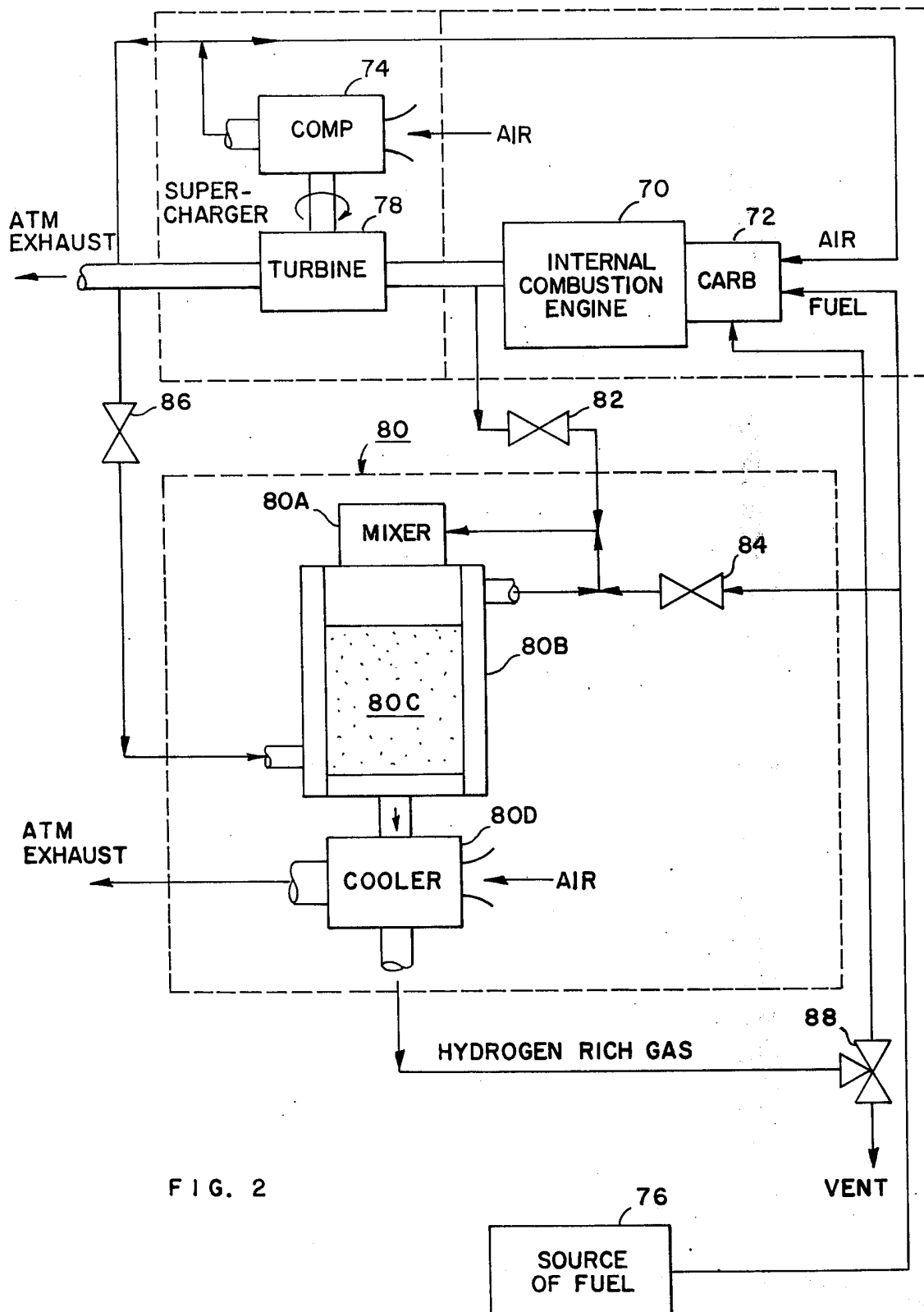


FIG. 1

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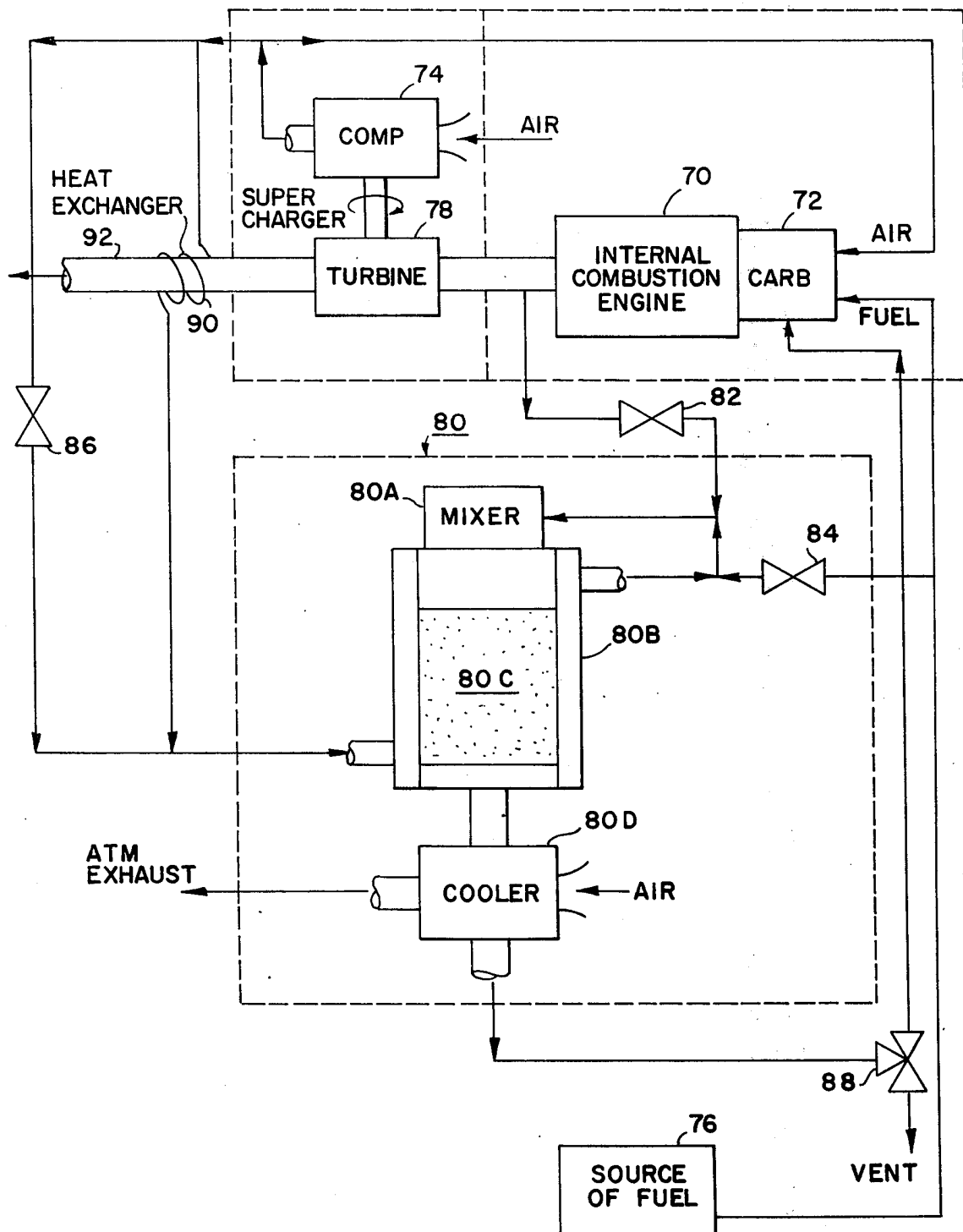
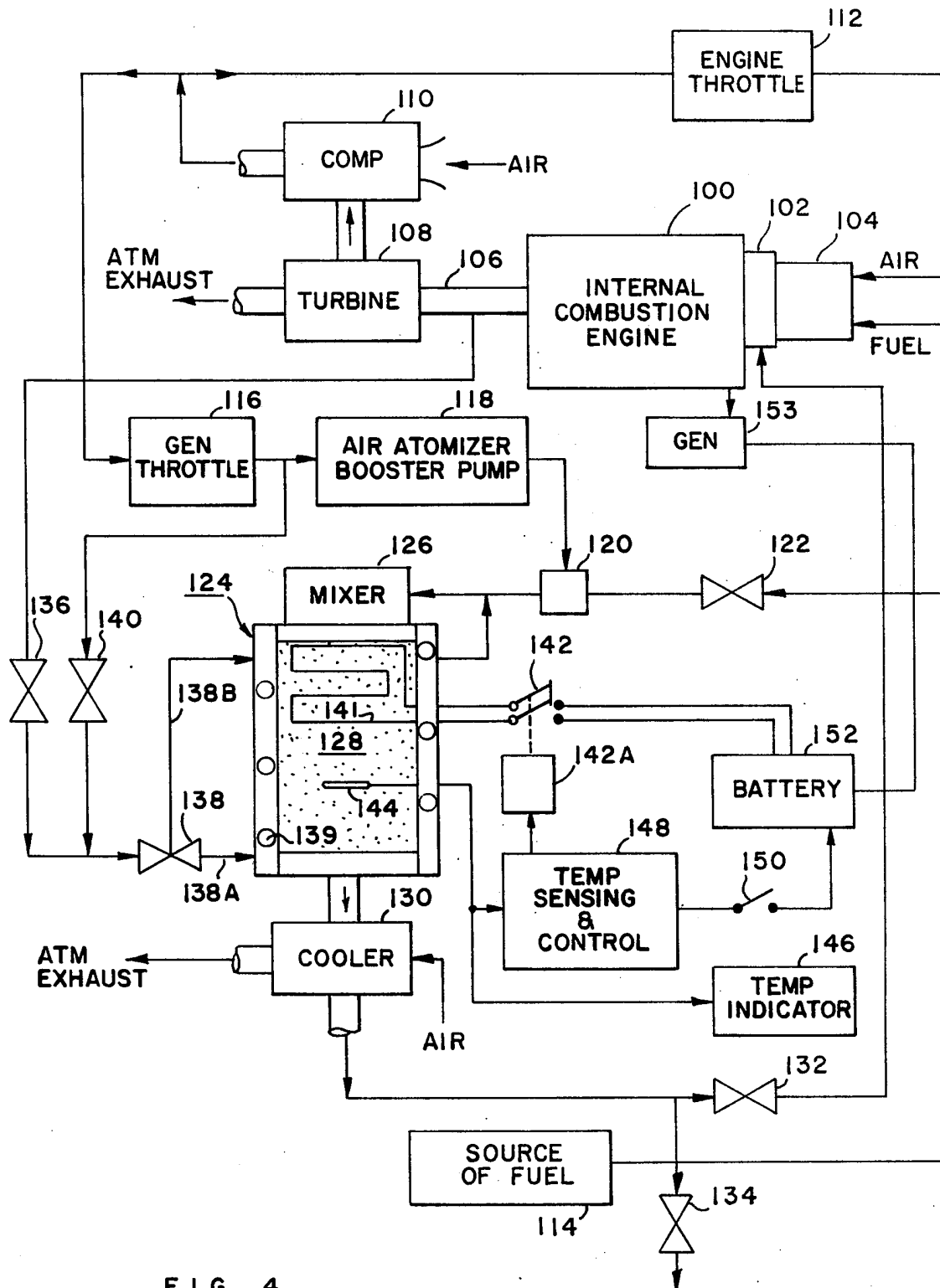


FIG. 3

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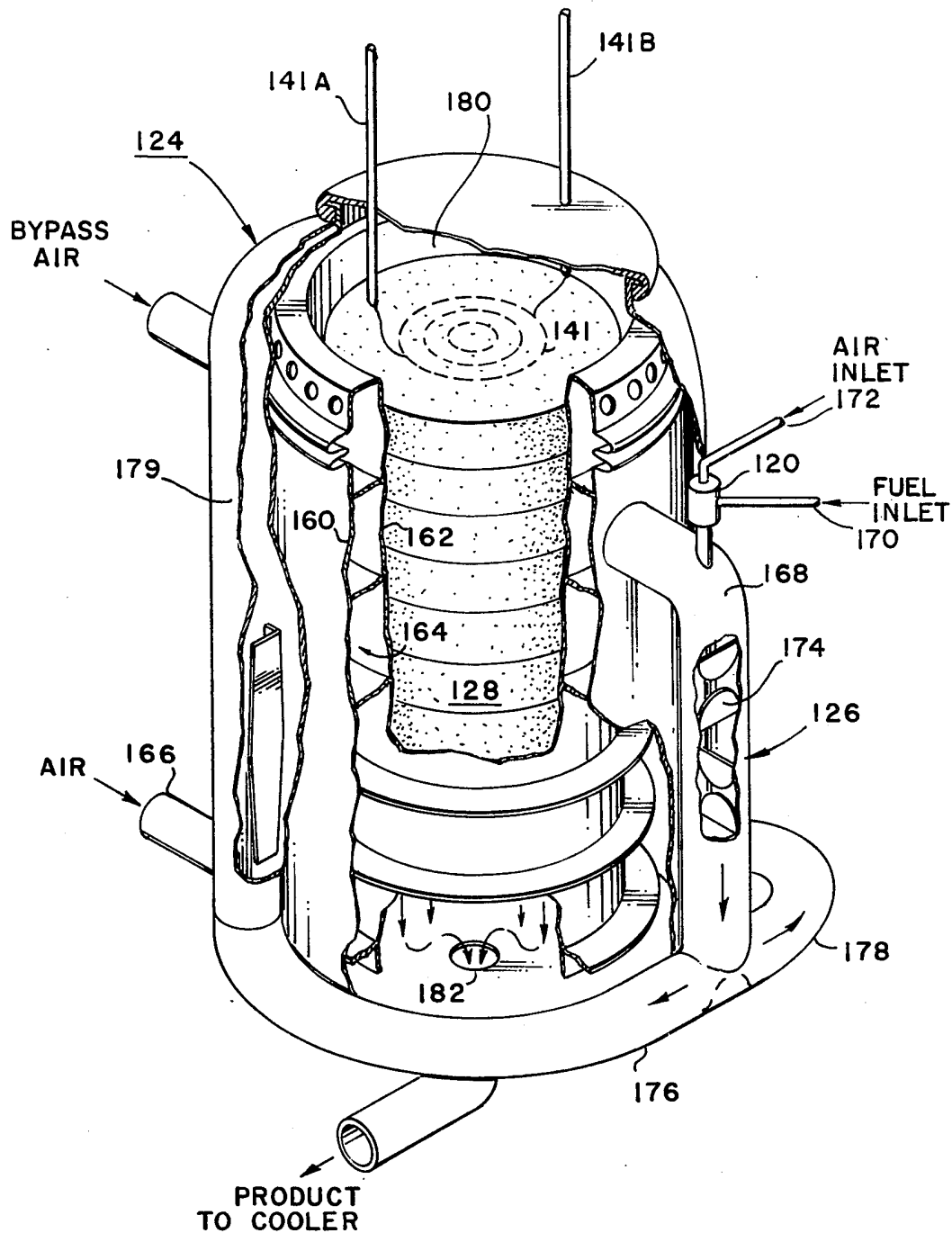


FIG. 5

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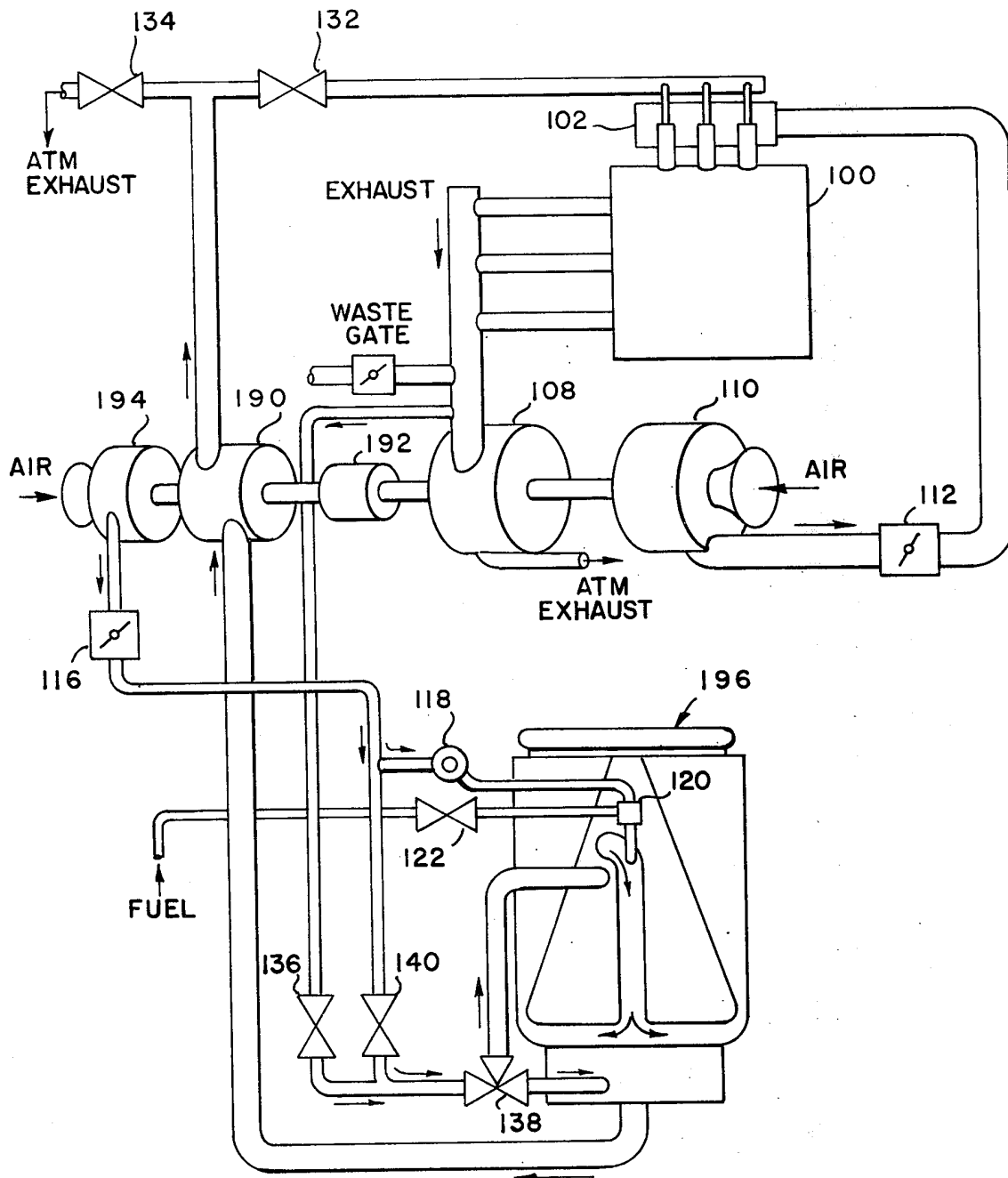


FIG. 6

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## START UP SYSTEM FOR HYDROGEN GENERATOR USED WITH AN INTERNAL COMBUSTION ENGINE

### ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the NASA Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457). 2457).

### BACKGROUND OF THE INVENTION

This invention relates to internal combustion engines, and more particularly to a system for supplying fuel to the engine.

In an application Ser. No. 487,156 filed July 10, 1974, now U.S. Pat. No. 3,982,910, by these inventors, which is entitled Hydrogen Rich Gas Generator, there is described and claimed a generator for producing hydrogen rich gas from hydrocarbon fuels. The generator has a catalytic bed containing particles of a partial oxidation catalyst, such as nickel, or platinum or silver oxide. A hydrocarbon fuel is mixed with air and then injected into a chamber where the mixture is ignited using a means, such as a spark plug. The ignited mixture produces a flame and gases which flow through the catalytic bed to heat it up to a required operating temperature. As the catalytic bed heats up beyond 900° F, the flame gradually moves into the catalytic bed and when a steady state temperature of 1800° F is reached there is no visible flame present and the requirement for igniting the air and hydrocarbon fuel mixture is no longer necessary, since ignition is caused to occur by the hot catalytic bed.

The catalytic bed converts the air and fuel mixture passing therethrough into hydrogen rich product gases which are then collected and mixed with fuel and air which is then fed into the cylinders of the internal combustion engine.

A preferred catalyst is a nickel catalyst. However, the manufacturer of this catalyst recommends that the nickel not be exposed to temperatures above 2200° F. It was previously indicated that start up requires first igniting gases with a burner, which gases are passed through the catalytic bed until it is heated to its light-off temperature, (the temperature at which the reaction starts). To keep the combustion gas temperature down, a rich combustion mixture is used with the flame temperatures on the order of 3000° F (hence the possibility that some of the catalyst is heated to higher than the 2200° F maximum). The 3000° F corresponds to an air/fuel mass ratio of approximately 10. To produce a lower temperature combustion requires using a lower air/fuel ratio. However, it is not feasible to use air/fuel ratios below 10 as this results in soot formation. Soot deposition on a catalyst, in turn, results in catalyst deactivation and can also cause plugging of gas passages in the catalyst. Further, the temperature above 2300° F, causes a degradation of the catalyst active surface so that some capability is lost with each cold start of the generator.

When a sufficient amount of catalyst surface has been heated above the light off temperature (800° -1000° F range for a nickel catalyst), the air/fuel ratio must be changed from the cold start value of 10 to the operating value of 5.2. This procedure will then cause the transition from a luminous start-up flame to flame-

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less operation within the catalyst bed. Switching the air/fuel ratio from 10 to 5.2 during start-up requires an appropriate control system which adds to the overall complexity and which reduces the overall reliability.

Accordingly, a start-up system which would avoid overheating the catalyst and the need for apparatus for changing the air/fuel ratio from a start-up value to an operating value would result in a less expensive catalytic converter, as well as one which avoids the possibility of damage or plugging of the catalytic converter bed.

### OBJECTS AND SUMMARY OF THE INVENTION

It is an object of this invention to provide a catalytic converter start-up system which eliminates the need for a start-up burner as well as the need for changing the air/fuel ratio from one value used at start-up to another value used during regular operation.

It is another object of the present invention to provide a new and improved start-up system for a hydrogen fuel generator using a catalytic converter.

Yet another object of this invention is the provision of a start-up system for a hydrogen generator using a catalytic converter, which avoids the possibility of damaging the catalytic converter.

The foregoing and other objects of the invention are achieved in an arrangement wherein the engine with which the hydrogen generator is associated is initially started in its usual manner. Energy generated by the engine is used to heat up the catalytic bed. The engine produces exhaust gas which is sufficiently hot so that it can be either applied directly to the catalytic bed of the hydrogen generator to rapidly heat it to the required start-off temperature, at which point the exhaust gas is no longer used, or the exhaust gas may be used to pre-heat air which is then applied to the catalytic bed to cause its temperature to rise to the start-off temperature. At that time the air can be turned off. Another catalytic converter preheat system in accordance with this invention is to imbed electrical heater wires in the catalytic bed and apply electrical current to the wires until the bed reaches the required temperature.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cross-sectional view of a hydrogen generator as described and shown in application Ser. No. 487,156 filed July 10, 1974, now U.S. Pat. No. 3,982,910, by these inventors.

FIG. 2 is a schematic drawing illustrating one embodiment of this invention.

FIG. 3 is a schematic drawing illustrating another embodiment of this invention.

FIG. 4 is a schematic drawing illustrating still another embodiment of this invention.

FIG. 5 is a pictorial drawing of a hydrogen generator suitable for use with the catalytic bed heating systems described, and

FIG. 6 is a schematic drawing of an improvement over FIG. 4.

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### DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a schematic drawing of a hydrogen generator using a catalytic converter and is identical with FIG. 10 in the previously mentioned application Ser. No. 487,156. It is shown for the purpose of assisting in providing a better understanding and appreciation of this invention. The hydrogen generator basically comprises three sections, a mixer section 10, a combustion section 12, and a preheater or heat exchange section 14. The combustion section and heat exchange section together effectively constitutes a hollow cylinder having an outer wall 16 and an inner wall 18 spaced therefrom. Suitable insulation 20, such as cast ceramic, is positioned therebetween. The heat exchanging section includes a plurality of hollow tubes, 22, 24, for example, which are spaced from one another and which extend from the combustion section to a collection space 26, leading to the exhaust flange 28.

A plurality of baffles, 30, 32, which are spaced from one another, extend from the opposite sides of the inner walls in a manner so that the air, which is introduced from a source of air 34, will follow a zig zag path through the space between the tubes until the air reaches an air exit passage 36, which is positioned at the opposite end from the air entrance was to the heat exchange region. In this manner the air comes in contact with the tubes through which hot hydrogen rich gases pass. The baffles 30, 32, provide for cross-flow of the air across these tubes and thus effectuate an effective heat transfer.

The air leaves the exit flange 36 and is directed into the mixer section 10. The air circulates around a nozzle 42 and passes through spiral tubes 11 into the combustion section 12. At start-up, a liquid hydrocarbon fuel from a source 38, is pumped through a two-way valve 40, into the mixer section. The mixer section has the start-up nozzle 42, which emits a spray of liquid droplets into the combustion chamber in combustion section 12. The air/fuel mixture in the combustion chamber is ignited by a spark plug 44, which is powered from a source 46. A partial oxidation reaction then occurs. A catalytic bed 48 is placed adjacent to the region where combustion takes place during start-up. This bed comprises a cylinder 50 which has a perforated top wall 52 and a perforated bottom wall 54, to permit hot gases to flow from the combustion region through the catalytic bed into the heat exchange section 14. The catalytic bed contains particles 56, of a partial oxidation catalyst such as nickel, deposited in a substrate such as aluminum pellets which serve to speed up the partial oxidation reaction of the hydrogen carbon with air, to yield a hydrogen rich gas. Other partial oxidation catalysts, such as palladium, platinum or silver oxide may also be used for the reaction of hydrocarbon and air.

During start-up, the air/fuel ratio sprayed into the combustion chamber is maintained above the vaporized fuel normal design value, such as 10. There is a temperature sensor 58, in the air exit flange, and when this sensor detects the fact that a preset temperature value has been exceeded by the preheated air, it controls the two-way valve 40 to prevent further application of fuel to the start-up nozzle in the burner and instead supplies the fuel to a fuel vaporization coil 60. Changes in the amount of fuel delivered to the burner and to the vaporizer are determined by the sizes of the two way valve exit parts. The coil 64 is wound on the

inner metal combustion shell or the inner wall 18 and is embedded in the insulation 20.

The vaporized fuel leaves the coil exit 62, and thereafter is mixed with the heated air stream coming out of the air exit flange 36. The pre-mixed vaporized fuel/air stream now passes through the mixer section 10 through the spiral tube 11, into the combustion chamber, where partial oxidation of the fuel takes place to produce a hydrogen rich gas. It should be noted that when the two-way valve 40 is switched to the vaporized fuel position, the air/fuel ratio is reduced to an operating value on the order of 5.2. While air temperature may be used to determine the proper time for operating the two-way valve so that the air/fuel mixture value is changed to the operating value, it is also possible to sense the catalytic temperature and when this reaches a predetermined value, the valve 40 may be operated to the run mode, from the start-up mode.

In accordance with this invention, the construction of the catalytic converter is considerably simplified. Other and better means are provided for bringing the catalytic bed to its start-up temperature. The embodiments of the invention which are described subsequently herein include an aircraft piston type internal combustion engine. However this should not be construed as a limitation on the invention, since those skilled in the art will readily understand how the invention may include any other type of internal combustion engine.

Referring now to FIG. 2, there may be seen a schematic diagram of an arrangement in accordance with this invention. An internal combustion engine, 70, has a carburetor 72, to which air is supplied from an air compressor 74, and fuel is supplied from a source of fuel 76. The compressor 74 may be driven by a separate electric motor, or may be driven by a turbine 78 which in turn is driven by exhaust gases from the internal combustion engine.

The hydrogen generator is included in the dotted rectangle indicated by reference numeral 80. It includes a mixer section 80A, a combustion section 80B, having a catalytic bed 80C and a cooling section 80D. The combustion chamber as shown in FIG. 1 may be omitted since it is not needed.

The engine is started in its usual manner, without mixing any hydrogen rich gas with the incoming fuel. A valve 82 is opened to permit some of the exhaust gas from the internal combustion engine to enter into the hydrogen generator by way of the mixer region 80A. A fuel valve 84, at this time, is closed, and an air valve 86, at this time, is also closed. A two-way valve 88, in one position vents the hydrogen gas generator, and in another position permits the hydrogen rich gas to be supplied to the carburetor of the internal combustion engine. The fraction of the hot engine exhaust gas which enters the mixer 80A, by way of valve 82, has a temperature on the order of between 1000° to 1200° F and heats up the catalytic bed quickly. The engine exhaust gas, which passes through the hydrogen generator at this time, is vented to the atmosphere through valve 88. When the catalytic bed has reached the temperature at which light-off occurs (approximately 900° F) the valve 82 is closed, and valve 86 is opened to permit a fraction of the air from the engine super charger to enter a heating jacket surrounding the catalytic bed of the hydrogen generator. The jacket heats the air received to a temperature, slightly higher than the ambient, which for steady state conditions is approximately 400° F. Fuel valve 84 is opened and valve 88 is operated at



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this time to the position which permits gas exiting from the generator to enter the carburetor of the engine. The fuel valve 84 is also opened at this time and the rate of fuel entering the mixer 80A is slowly increased. The fuel is completely vaporized in the mixer by the heated air. The vaporizer fuel/air mixture entering the catalytic bed 80C will start to react with the catalyst and the subsequent temperature in the bed will reach a steady state at approximately 1800° F.

The exiting hydrogen-rich product gas passes through the supplementary air cooled product-gas cooler 80D and exits the hydrogen generator at approximately 500° F or below. It is fed to the engine carburetor through the valve 88.

By way of example, a carburetor suitable for use for enabling engine start-up and for thereafter mixing the hydrogen rich product gas with the fuel and air in the proper proportions is shown and described in a patent by J. Rupe U.S. Pat. No. 3,906, 913.

FIG. 3 shows another arrangement for heating the catalytic bed, using a heat exchanger which extracts heat from the engine exhaust gas. Apparatus which serves the same function as the apparatus shown in FIG. 2 has the same reference numerals applied thereto. During start-up, valves 84 and 86 are closed and valve 88 is set to its venting position. Some of the air from the compressor 74 passes through a heat exchanger, which may comprise pipe coils 90, wrapped around the exhaust pipe 92 through which the hot combustion gas exhausted from the internal combustion engine passes. The air passing through the wrap around pipes 90, comprising the heat exchanger, is delivered to the hydrogen generator heating jacket and exits from the heating jacket into the mixer 10, as previously described. The air is at a temperature between 900°-1000° F when it reaches the heating jacket. When the catalytic bed reaches the light-off temperature, valve 84 is opened to permit fuel to be added to the hot air, and the vaporized fuel/air mixture then starts to react on the catalytic bed. At that time, valve 86 is opened so that air from the compressor will bypass the heat exchanger and enter into the heating jacket of the catalyst to be heated by the catalyst. The air coming out of the heating jacket is then mixed with the incoming fuel. The air has a temperature on the order of 400° F, while the temperature of the catalytic bed rises to 1800° F.

The primary difference between the embodiments of the invention shown in FIGS. 2 and 3 is that in FIG. 2, a catalytic bed is preheated with hot air rather than with combustion gas as in FIG. 2. Exposure to air results in adsorption of oxygen in the catalyst which results in a somewhat lower light-off temperature compared to heating up with combustion gas. The advantage of a lower light-off temperature can be balanced against the extra heat exchanger requirement.

When it is desired to turn off the engine and the catalytic converter, it is desirable to purge the catalytic converter. While this may be done by turning off fuel valve 84 and turning valve 88 to its venting position, it is more desirable to purge the catalytic bed with air having a reduced oxygen content. This can be done by opening valve 82, which admits exhaust gas to the mixer 80A.

The valves shown in FIGS. 2 and 3 can be operated between their open and closed positions either manually, by observing on a suitable indicator (not shown) the temperature of the catalytic bed. When it reaches

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the light off temperature, valve 82 is turned from its open to its closed position and valves 84 and 86 are opened from their closed positions. Valve 88 is operated from the vent position to the position at which it feeds back hydrogen rich product gas to the carburetor. Alternatively, a sensing device in the catalytic bed can be used to control the valves, which may be solenoid actuated, so that they can be electrically operated between their closed and opened positions. The technique for controlling solenoid operated valves from a temperature sensing device is well-known and need not be shown here.

Referring now to FIG. 4, there may be seen a schematic diagram of another embodiment of the invention. The systems shown can either use exhaust gases alone for preheating the catalytic bed, or a system using electrical heating wires in the bed for preheating, or a combination of both if desired.

Schematically represented in FIG. 4 is an internal combustion engine 100, having a manifold 102 for distributing a fuel/air mixture to the engine cylinder and a carburetor 104. The engine exhaust gases are guided through a tube 106 to a gas turbine 108, which drives an air compressor 110. Also represented is the engine throttle 112. Fuel, from a source 114 is fed to the carburetor of the engine, and air from the air compressor 110, is fed through the engine throttle into the carburetor to be mixed with the fuel.

Air from the compressor is also fed to another throttle 116, called the generator throttle. This controls the amount of air that is fed to an air atomizer booster pump 118 and to a generator main air supply valve 140. The air output from the booster pump is fed to a fuel atomizer 120. The fuel atomizer 120 will receive fuel from a source of fuel 114 when a valve 122 is open. Heated air which has circulated around the hydrogen generator, together with the atomized fuel are fed to the mixer 126 where the heated air causes the atomized fuel to be vaporized. The mixture of vaporized fuel and air is fed from the mixer 126 to the catalytic bed 128, where the reaction converting the incoming air fuel mixture into a hydrogen rich product gas, takes place. The output from the hydrogen generator is then passed through an air cooled cooler 130. The hydrogen rich product gas which passes through the cooler back is then fed to the engine manifold 102, through a valve 132, when this valve is open. The output of the hydrogen generator can be fed to the exhaust when an atmospheric exhaust valve 134 is opened and valve 132 is closed.

For preheating the catalytic bed, exhaust gas from the engine is fed through a valve 136, to a second three-way valve 138. The three-way valve has two positions, one position opens a passageway, designated by 138A, which leads to a spiral passageway 139 circulating around the catalytic bed. The second position closes passageway 138A and opens a passageway 138B which leads to the top of the container holding the catalytic bed. When the valve 138 is in the position 138A, exhaust gas is permitted to flow through the spiral passageway 139 then into the mixer 126. In this way the hot engine exhaust gas heats the bed up to the operating temperature. The exhaust gas passes then through the bed, through the cooler and then out through valve 134 to the atmosphere.

The air output of the generator throttle valve 116 is also fed into the valve 138 through a valve 140, when it is opened. Valve 136 is closed and valve 140 is opened,

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when the catalytic bed reaches its operating temperature. The air passing through valve 140 also passes through valve 138 and around the spiral passageway so that this air is preheated. This is the air that is then delivered to the mixer.

Upon shutdown of the hydrogen generator, it is desirable to purge the generator of hydrogen rich gas and cool the catalyst quickly. Purging with clean air, should be avoided, and it can result in overheating the catalyst by too rapid oxidation of the catalytic agent (nickel or platinum). In accordance with this invention, when purging is desired, just before engine shutdown, the valve 140 which admits air from the compressor is closed, and the valve 136 is opened. Valve 138 is turned to the position feeding passageway 138B. As a result inert exhaust gas is passed directly through the catalytic bed, bringing its temperature down from the operating temperature to the exhaust gas temperature. As a result, the engine exhaust gases can serve as both a start-up heating and inert cool down media.

An alternative system to preheating with exhaust gas is to embed electrical heating wires, such as nichrome wire coils 140, in the upstream  $\frac{1}{2}$  of the catalytic bed. Application of power on the order of 1 kilowatt to the heating wires can heat enough of the catalyst above the minimum temperature of 800° F in 20-30 seconds to sustain the reaction at the running air/fuel ratio of 5.2. The heating wires 140 are connected to a solenoid operated switch 142. The solenoid is represented by 142A. A battery 152 applies power through the switch 142, when closed, to the heating wires 140. The battery is charged in well known fashion by a generator 153 which is driven by the engine. A temperature sensor 144, which is also embedded in the catalytic bed, is connected to both the temperature indicator 146 and to a temperature sensing and control circuit 148. A manually operated switch 150 is used to activate the temperature sensing and control circuit by connecting it to a source of power such as a battery 152. The temperature sensing and control circuit then energizes the solenoid 142A whereupon switches 142 are closed. As

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a result, power is supplied to the heating wires 140. When the catalytic bed 128 has reached the temperature required to sustain the reaction, the temperature sensor 144 actuates the temperature sensing and control circuit to deactivate the solenoid 142A whereby the switch 142 is open. The temperature is also indicated on a temperature indicator 146. At this time the switch 150 may be opened so that when the engine is shutdown the drop in temperature of the catalytic bed will not cause the temperature sensing control circuit to operate the solenoid 142A again. The temperature sensor may be any known device which such as a thyristor whose resistance changes with temperature. This can cause a predetermined voltage drop thereacross or current flow therethrough to de-energize a relay in the temperature sensing and control device which is energized when switch 150 is closed.

In order to reduce the electrical power and time required to reach start-up temperature, and also in order to reduce the impedance to air flow through the catalytic bed, instead of using a pellet type catalyst, a monolithic type catalyst is preferred. The monolithic type catalyst is a honeycomb or porous structure. The power and time required to reach start-up temperature of the monolithic type catalyst is reduced by as much as 50% over the pellet type catalyst, because of the reduced mass required per unit of exposed catalytic surface.

The following table shows the settings for the various valves during each of the preheating modes which are possible of the arrangements shown in FIG. 4. These include the start-up of the generator using both the electrical and exhaust preheating mode, generator start-up using the exhaust mode. The settings of the valves when the generator reaches steady state operation is also shown. These then follows a showing of the setting of the valves for normal shut-down and for emergency shut-down. Then there is a listing of the components whose operation is shown in the chart followed by an explanation of the symbols which are used.

GENERATOR OPERATING SEQUENCE COMPONENT									
MODE		136	140	138	122	134	136	118	142A
ENGINE START & TAKE-OFF		C	C	P	C	C	O	DE	DE
GENERATOR STARTUP (ELECT.+EXH.)	a)	O	C	↓	C	C	O	DE	DE
	b)	C	C		C	C	O	DE	E
	c)	C	O		O	O	C	E	DE
GENERATOR STARTUP (ELECT.)	a)	C	O		O	O	C	E	E
	b)	C	O		O	O	C	E	DE
GENERATOR STARTUP (EXH.)	a)	O	O	↓	O	O	C	E	DE
	b)	C	O		O	O	C	E	DE
STEADY STATE		C	O	B	O	O	C	E	DE
SHUTDOWN (NORMAL)	a)	C	C	P	C	C	O	DE	DE
	b)	O	C	P	C	C	O	DE	DE
	c)	C	C	P	C	C	O	DE	DE
SHUTDOWN (EMERGENCY)		C	O	P	C	C	O	DE	DE

## COMPONENTS:

SHUTOFF VALVES, AIR, 138,140 EXHAUST, 136, FUEL 122

PRODUCT 134,136

THREE WAY VALVE 138.

FUEL ATOMIZER AIR PUMP 118

HEATER SOLENOID 142A

## SYMBOLS:

C — CLOSED  
O — OPENP — PREHEAT  
B — BYPASSDE — DE-ENERGIZED  
E — ENERGIZED

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It will be noted that the engine start and take off occurs first, thereafter there is a 3-step generator start-up process when a combined electrical and exhaust preheat process is used. A 2-step start-up is needed only when the electrical process is used. A 2-step start-up is needed also only when the exhaust process is used. A 3-step normal shutdown process is used also. As indicated previously, the valves can be solenoid operated and their opening and closing can be actuated either manually or by automatic sequencing in response to a stepper switch or electronic counter that is actuated either in response to catalytic bed temperature or time delay, or a combination of both.

FIG. 5 is a drawing, in perspective and partially cut away, of a hydrogen generator, in accordance with this invention. The parts of the generator which are similar to the parts represented in FIG. 4 bear the same reference numerals. The electrical heating wires 140 are connected to two input terminals respectively 140A, 140B. The top end of the chamber 124 is the input to the bed and the bottom end is the output 124. The container includes an inner pair of walls respectively 160, 162, with the catalytic bed 128 being adjacent to the walls 162. A spiral passageway 164, is established between the pair of walls, and incoming air exhaust gases are directed from an inlet port 166 to the bottom of the spiral passageway. It will flow upwardly along the catalytic bed, and will then flow out into a pipe which is part of the mixer 126.

At the top of this pipe is the fuel atomizer 120 with the two incoming pipes respectively 170, 172, serving as fuel inlet and air inlet pipes. The mixer pipes contains a plurality of baffles 174, which are disposed in a manner to insure a through mixing of the air received from the spiral passageway 164 with the atomized fuel to insure vaporization of the atomized fuel. The air/fuel mixture then flows into two branching pipes respectively 176, 178, which lead into the passageway defined between the wall 160 and an outer wall 179, which surrounds the entire generator, thus, insuring uniform flow to the catalytic bed. The passageway between the walls leads into the input end or top end 180 of the chamber 124 which adjacent the leading side of the catalytic bed. The air/fuel mixture then passes through the catalytic bed and then not through an exit port 182, to the cooler portion of the hydrogen generator, which is not shown here.

FIG. 6 is a schematic pictorialized drawing of a preferred embodiment of the invention. It comprises a modification of the arrangement represented by FIG. 4, or one of the preceding drawing figures, and therefore structure having similar functions to the structures shown in FIG. 4 will bear the same reference numerals.

The modification comprises the addition of a small turbine 190, which upon engine startup, is driven through an overriding clutch 192 by the turbine 108 driven by the engine exhaust gas. The turbine 190 drives an air compressor 194 whose sole function is to provide air for the hydrogen generator 196 and for driving the air atomizer booster pump.

The hydrogen generator output is first fed to the turbine 190 and after passing therethrough, is applied to the atmospheric exhaust valve 134 and to the valve determining feed of hydrogen product gas to the engine. When the hydrogen product gas becomes hot enough to power the turbine 190, the turbine is driven by the hydrogen generator output and the drive from the turbine 108 is effectively disconnected.

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In the case of engines which do not have turbines, the override clutch 192 may be driven directly from the engine.

The advantages of the addition of a small turbine driven air compressor as shown in FIG. 6 are that it improves engine generator efficiency by eliminating the requirement for an engine driven air pump to supply air to the hydrogen generator at 10 psig, where there is not supercharger for the engine, and in those cases where there is a supercharger, it eliminates the requirement for pumping the total air flow to a higher pressure, as required by the generator, whereas engine pressure requirements are significantly less.

It enables an increase in the generator system operating pressure level from 17 to 50 psia, which permits a reduction in generator size as a result of increased reactant density, and improves catalyst activity which is a function of operating pressure level. It also increases the generator system efficiency by turbo-charger utilization of 37% of the sensible heat in the generator product normally transferred to the engine cooling system by means of the product heat exchanger. Thereby, a reduction in the size of coolant pumping power requirements for the hydrogen generator product system is provided.

While the description of the embodiments of the invention are in connection with supercharged engines, i.e. those using turbine driven air compressors, this not to be construed as a limitation on the invention since it is believed to be obvious to those skilled in the art how this invention can be used with and for internal combustion engines not having turbine driven air compressors.

There has accordingly been shown and described herein a novel and useful system for startup heating the catalytic bed of a hydrogen generator from heating energy developed by an internal combustion engine.

We claim:

1. In combination, an internal combustion engine, which produces hot exhaust gas when operative, and a hydrogen product gas generator,
  - said internal combustion engine having means for applying an air/fuel mixture to said engine, and means attached to the engine for producing air under pressure,
  - said hydrogen product gas generator including first walls defining a hollow chamber, said chamber having an input end, an output end, and a center portion,
  - a catalytic bed positioned in said center portion,
  - second walls forming a spiral passageway around said first walls, said spiral passageway having an input end and an output end,
  - fuel atomizer means having a fuel input, an atomizing air input, a vaporizing air input and output,
  - air/fuel mixer means having a first input connected to said fuel atomizer output, a second input adjacent said first input connected to said spiral passageway output end, and an output connecting to said hollow chamber input end,
  - first valve means having one position for permitting hot exhaust gas to be applied from said engine to said spiral passageway input end to thereby heat the enclosed catalytic bed to an operating temperature, and a second position for blocking further gas application,
  - means defining a source of liquid hydrocarbon fuel,

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second valve means having one position for applying fuel from said source to said fuel atomizer means fuel input and a second position for blocking said fuel input,

means for applying air from said means attached to the engine to said fuel atomizer means atomizing air input for atomizing fuel applied to said fuel atomizer means,

third valve means having a first position for applying air from said means attached to the engine to said spiral passageway input end and a second position for terminating the application of air, and

fourth valve means having a first position for connecting said hollow chamber output end to said means for applying an air/fuel mixture to said engine, and a second position for venting the hollow chamber output to the atmosphere whereby following engine start up, said first valve means is placed in its first position, said second, third and fourth valve means are placed in their second positions, thereby hot engine exhaust gas can heat said catalytic bed up to its operating temperature and then be exhausted to the atmosphere, and upon the catalytic bed reaching its operating temperature, said first valve means is placed in its second position and said second, third and fourth valve means are placed in their first positions whereby vaporized hydrocarbon fuel and air are applied to said catalytic bed to produce a hydrogen rich product gas which is applied to said engine.

2. In the combination recited in claim 1 wherein said means for applying an air/fuel mixture said engine includes an intake manifold, and

said fourth valve means, when in its first position connects said hollow chamber output end to said intake manifold.

3. In the combination recited in claim 1 wherein said catalytic bed is a monolithic catalytic bed.

4. In the combination recited in claim 1 wherein said means for producing air under pressure by said engine comprises

gas driven turbine means including means for driving said turbine from said engine until it is gas driven, means for connecting said gas driven turbine means between said hollow chamber output end and said fourth valve means for driving said gas driven turbine means with the gas output from said hydrogen generator and thereafter applying the gas output which has driven said turbine means to said fourth valve means,

air compressor means driven by said gas driven turbine means,

said means for applying air from said engine to said fuel atomizer means includes

means for applying output from said air compressor means to said fuel atomizer means, and

means for applying output from said air compressor means to said third valve means.

5. In the combination recited in claim 1 wherein there is included

means for purging said catalytic bed with hot exhaust gas before discontinuing the use of said hydrogen product gas generator.

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6. In combination, an internal combustion engine, which produces hot exhaust gas when operative, and a hydrogen product gas generator,

said internal combustion engine having means for applying an air/fuel mixture to said engine, and means connected to the engine for producing air under pressure,

said hydrogen product gas generator including first walls defining a hollow chamber, said chamber having an input end, an output end, and a center portion,

a catalytic bed positioned in said center portion, heating wire means in said bed,

means for energizing said heating wire means to heat said catalytic bed to its operating temperature and for de-energizing said heating wire means when it has reached its operating temperature,

second walls forming a spiral passageway around said first wall, said spiral passageway having an input end and an output end,

fuel atomizer means having a fuel input, an atomizing air input, a vaporizing air input and an output,

air/fuel mixer means having a first input connected to said fuel atomizer output, a second input adjacent said first input connected to said spiral passageway output end, and an output connecting to said hollow chamber input end,

means defining a source of liquid hydrocarbon fuel, first valve means having a first position for applying fuel from said source to said fuel atomizer means fuel input, and a second position for blocking said fuel input,

means for applying air from said engine to said fuel atomizer means atomizing air input for atomizing fuel applied to said fuel atomizer means,

second valve means having a first position for applying air from said engine to said spiral passageway input end and a second position for terminating the application of air, and

third valve means having a first position for connecting said hollow chamber output end to said means for applying an air/fuel mixture to said engine, and a second position for venting the hollow chamber output to the atmosphere whereby following engine start up, and after said catalytic bed has been heated to its operating temperature by said heating wire means, said first, second and third valve means are operated from their second to their first positions whereby the air from said engine is pre-heated by said catalytic bed vaporizes said atomized fuel and this is applied to said catalytic bed to be converted to a hydrogen rich product gas which is fed to said means for applying an air/fuel mixture to said engine.

7. In the combination recited in claim 6 wherein said means for applying an air/fuel mixture to said engine includes an intake manifold, and

said third valve means when in its first position connects said hollow chamber output to said intake manifold.

8. In the combination recited in claim 6 wherein said catalytic bed is a monolithic catalytic bed.

9. In the combination recited in claim 6 wherein there is included:

means for purging said catalytic bed with hot exhaust gas for discontinuing the use of said hydrogen product gas generator.

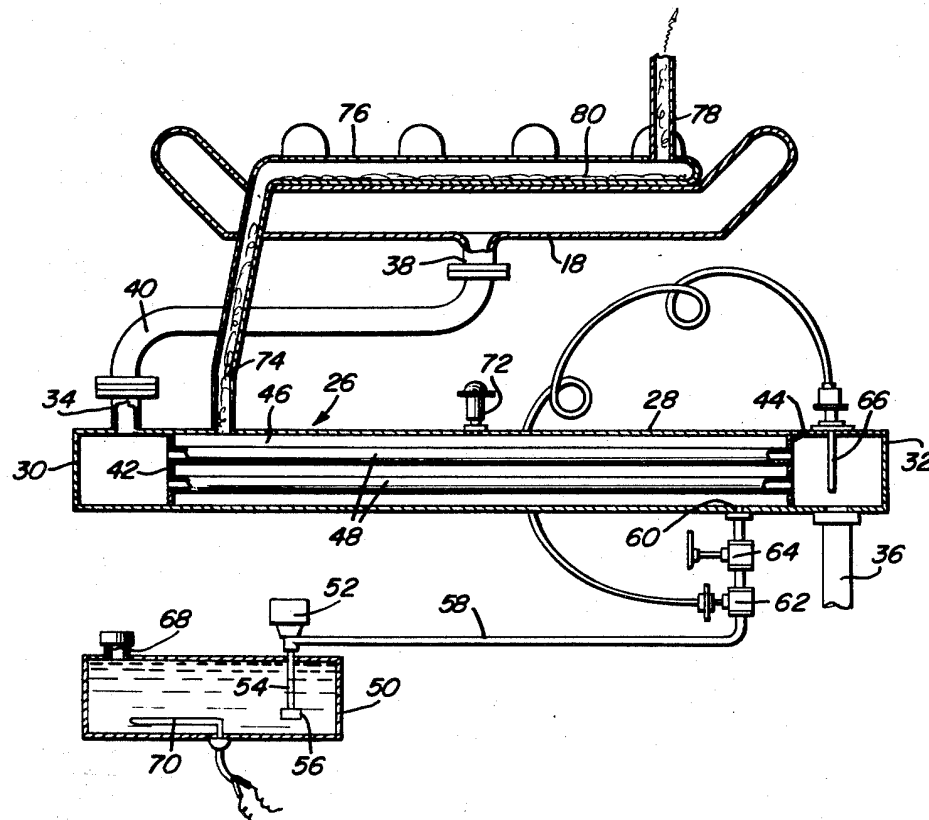
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**United States Patent** [19]**Schreiber**[11] **4,037,568**[45] **July 26, 1977****[54] EXHAUST HEATED HYDROGEN AND OXYGEN PRODUCING CATALYTIC CONVERTER FOR COMBUSTION ENGINE****[76] Inventor:** Edward T. Schreiber, 7400 Lyndale Ave. South, Minneapolis, Minn. 55423**[21] Appl. No.:** 567,177**[22] Filed:** Apr. 11, 1975**[51] Int. Cl.<sup>2</sup>** ..... F02B 43/08; F02D 19/00**[52] U.S. Cl.** ..... 123/3; 123/1 A; 123/25 J; 123/25 P; 123/DIG. 12**[58] Field of Search** ..... 123/1 A, 3, DIG. 12, 123/119 E, 25 J, 25 P, 122 E, 122 AA**[56] References Cited****U.S. PATENT DOCUMENTS**

1,452,213	4/1923	Nelson	123/122 AB
1,471,745	10/1923	Lundgren	123/122 AA
1,630,048	5/1927	Balachowsky	123/122 AA
1,784,924	12/1930	Berry	123/122 E
1,966,345	7/1934	Harrell	123/121
2,295,209	9/1942	Guiles et al.	123/3 X
3,653,364	4/1972	Bogan	123/119 E
3,828,736	8/1974	Koch	123/3
3,939,806	2/1976	Bradley	123/3

**Primary Examiner**—Carroll B. Dority, Jr.**Assistant Examiner**—William Randolph**Attorney, Agent, or Firm**—Clarence A. O'Brien; Harvey B. Jacobson**[57] ABSTRACT**

A steam generator is provided in operative association with a source of water and the exhaust system of a combustion engine including an air induction system provided with primary fuel inlet structure and supplemental fuel inlet structure. The steam generator derives its heat for converting water into steam from the exhaust system of the combustion engine and the steam generator includes a steam outlet communicated with and opening into one end of an elongated tubular housing disposed in good heat transfer relation with the exhaust system of the combustion engine and having a gas outlet at its other end communicated with the supplemental fuel inlet of the induction system. The tubular housing has iron filings disposed therein and is in such heat transfer relation with the exhaust system of the combustion engine so as to elevate the temperature of steam passing therethrough and to heat the iron filings to the extent that passage of the heated steam over the heated filings will result in hydrogen and oxygen gas being produced in the tubular housing for subsequent passage to the supplemental fuel inlet of the combustion engine induction system.

**3 Claims, 2 Drawing Figures**

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Fig. 1

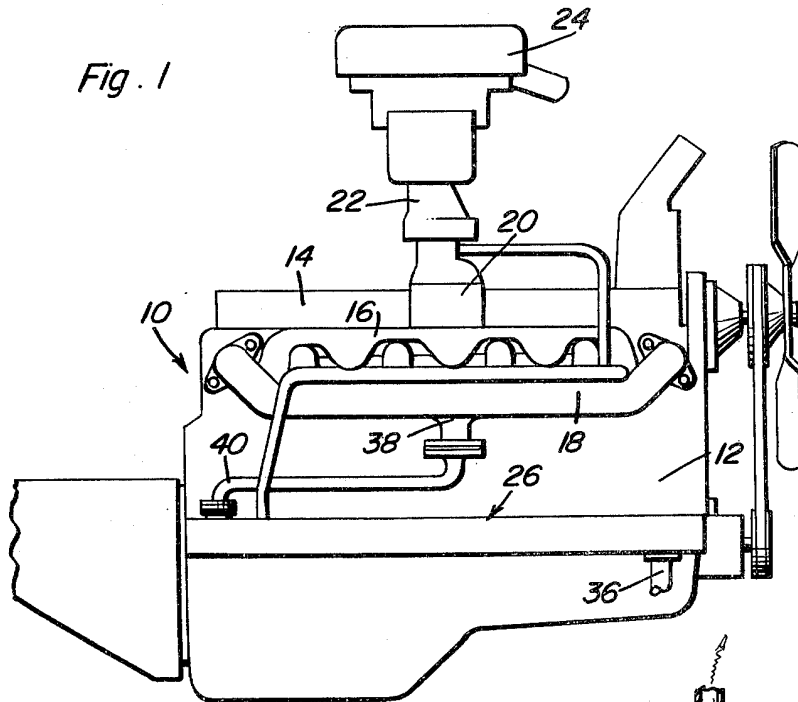
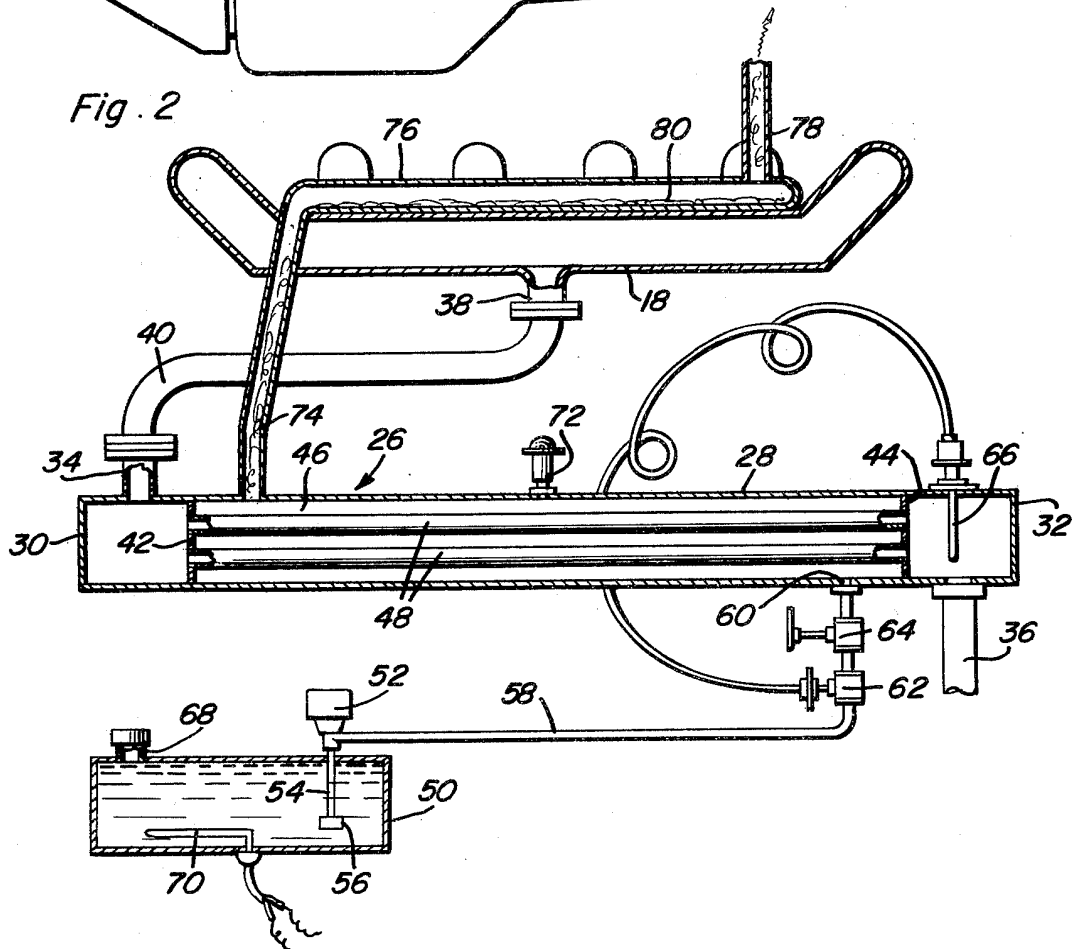


Fig. 2



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## EXHAUST HEATED HYDROGEN AND OXYGEN PRODUCING CATALYTIC CONVERTER FOR COMBUSTION ENGINE

### BACKGROUND OF THE INVENTION

Various structures in the form of catalytic converters have been heretofore provided for converting high temperature steam into hydrogen and oxygen gas. However, these previously constructed catalytic converters do not include some of the features of the instant invention whereby a hydrogen and oxygen gas generating catalytic converter may be conveniently operatively associated with a combustion engine in order to generate supplemental fuel for burning in the engine.

### SUMMARY OF THE INVENTION

The catalytic converter of the instant invention is specifically constructed for ease in operative association with a conventional vehicle internal combustion engine in a manner such that water converted into steam by utilizing the heat of the exhaust gases from the engine may be broken down, at least to a great extent, into its hydrogen and oxygen components and these components, in gaseous form, may be ducted to the induction system of the combustion engine and utilized as a supplemental fuel therefor.

The main object of this invention is to provide a means whereby the usual maximum power output of a combustion engine may be increased.

Another important object of this invention is to provide an apparatus in accordance with the preceding objects whereby the amount of power developed by the associated combustion engine may be produced partially as a result of the burning of hydrogen and oxygen gases as a supplemental fuel in the engine and with the hydrogen and oxygen gases being produced as a result of converting relatively inexpensive water into its hydrogen and oxygen components.

Still another object of this invention is to provide a converter of the catalytic type and in operative association with the heated exhaust system of a combustion engine in a manner such that water may be readily converted into its hydrogen and oxygen components by an inexpensive method.

A final object of this invention to be specifically enumerated herein is to provide an apparatus in accordance with the preceding objects and which will conform to conventional forms of manufacture, be of simple construction and easy to use so as to provide a device that will be economically feasible, long lasting and relatively trouble free in operation.

These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view of a conventional form of internal combustion engine and with the catalytic converter of the instant invention operatively associated therewith; and

FIG. 2 is a fragmentary enlarged side elevational view of the catalytic converter with portions thereof being broken away and illustrated in vertical section

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and in operative association with various exhaust system components of the combustion engine.

### DETAILED DESCRIPTION OF THE INVENTION

Referring now more specifically to the drawings, the numeral 10 generally designates a conventional form of motor vehicle internal combustion engine having a block 12, a cylinder head 14 secured over the top of the block and intake and exhaust manifolds 16 and 18. The intake manifold 16 includes an upwardly projecting riser 20 comprising an inlet for the manifold 16 and a conventional carburetor 22 is mounted on top of the riser and has an air cleaner 24 operatively associated with its inlet.

A steam generator referred to in general by the reference numeral 26 is provided and includes an elongated housing 28 closed at its opposite ends as at 30 and 32 and provided with an exhaust gas inlet 34 at one end and an exhaust gas outlet 36 at its other end.

The exhaust manifold 18 includes an outlet neck 38 and the outlet neck 38 is communicated with the inlet 34 by means of an exhaust pipe 40. Further, the interior of the housing 28 includes a pair of opposite end transverse partitions 42 and 44 secured thereacross in positions spaced along the housing 28 toward the longitudinal center thereof from the exhaust inlet 34 and the exhaust outlet 36. The interior of the housing 28 disposed between the partitions 42 and 44 defines a steam chamber 46 and a plurality of tubes 48 extend between and open through the partitions 42 and 44, the ends of the tubes 48 being secured through the partitions in fluid-tight sealed engagement therewith. Accordingly, the tubes 48 communicate the opposite ends of the housing 28 into which the exhaust inlet and exhaust outlet open.

A water supply reservoir 50 is provided and a pump 52 is supported from the reservoir 50. The pump 52 includes an inlet pipe 54 projecting down into the reservoir 50 and provided with a foot valve 56. Further, the pump 52 includes an outlet line 58 opening into the steam chamber 46 as at 60 and the line 58 includes a thermostatically controlled valve 62 as well as a manually controlled valve 64 serially connected therein, the thermostatically controlled valve 62 being thermoresponsive and including a remote temperature sensing actuator 66 disposed in the end of the housing 28 into which the outlet 36 opens.

The reservoir 50 includes a filler neck 68 and an internal heater 70 for heating the water within the reservoir 50 to a point slightly below the boiling point. The heater 70 and the pump 52 are electrically actuated and may receive electrical current from any suitable source of electrical potential (not shown).

The housing 28 includes an excess pressure relief valve 72 for venting the steam chamber 46 and a steam line 74 opens into an upper portion of the steam chamber 46 at its inlet end and into one end of an elongated hollow tubular member 76. The other end of the hollow tubular member 76 has the inlet end of a gas supply line 78 opening thereinto and the outlet end of the gas supply line 78 opens into the interior of the riser 20 below the carburetor 22.

The tubular member 76 extends along the upper surface of the exhaust manifold 18 in good heat transfer relation therewith and has a quantity of iron filings 80 disposed therein.

In operation, the engine 10 is initially started by utilizing the conventional carburetor 22. Then, after the

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exhaust system of the engine 10 has become heated and the heater 70 within the reservoir 50 has been in operation for a sufficient time to heat the water within the reservoir 50 to a point just below the temperature at which water boils, the pump 52 may be actuated and water is thereby pumped from the reservoir 50 into the steam chamber 26 whereupon the exhaust gases from the manifold 18 passing through the tubes 48 will further heat the water in order to convert the same into steam. The valve 64 remains open at all times except when it is desired to maintain the catalytic converter inoperative and the valve 62 is under the control of the temperature sensing actuator 66 thereof in order to open the valve 62 in response to an increase in temperature and to close the valve 62 in response to a drop in temperature being sensed. As steam is generated in the steam chamber 26 it is vented through the line 74 into the tubular member 76 and is further heated. In addition, the iron filings 80 within the tubular member 76 are highly heated and the passage of steam through the tubular member 76 in intimate contact with the iron filings 80 causes the steam, by catalytic action, to be broken down into its hydrogen and oxygen components. Thereafter, the hydrogen and oxygen components are ducted through the gas supply line 78 and discharged into the induction passages of the engine 10. Of course, the induction of hydrogen, and oxygen gas into the engine 10 will increase its power capacity and also result in a savings of conventional fuel such as gasoline for a given power output.

The foregoing is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

What is claimed as new is as follows:

1. In combination with an internal combustion engine of the type having an air induction system including primary fuel inlet means and an exhaust system for combustion gases, supplemental fuel inlet means for said induction system including steam generator means having a steam outlet, a gas generator housing having a predetermined amount of iron filings disposed therein and fluid inlet and outlet means, means connecting said steam outlet with said fluid inlet means, and means communicating said fluid outlet means with said supplemental fuel inlet means, said exhaust system including portions which are heated to a high degree as a result of operation of said engine, said heated portions of said exhaust system being in good transfer relation with said gas generator housing for heating the internal surfaces thereof and said iron filings, the passage of steam through said housing and in intimate contact with the heated iron filings in said housing serving to further elevate the temperature of said steam and to produce hydrogen and oxygen gas for passage through said housing outlet and to said supplemental fuel inlet means, said exhaust system including an elongated exhaust manifold, said generator housing comprising an elongated tubular member through whose opposite end portions said fluid inlet and outlet means open, said tubular member being disposed in good heat transfer relation with the external surfaces of said exhaust manifold, said steam generator including a horizontally elongated housing provided with a pair of inner transverse

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partitions spaced from the opposite ends of said steam generator housing and dividing the latter into opposite end chambers and a central disposed between said partitions, a plurality of elongated horizontal heat transfer tubes extending through said central chamber and opening into said end chambers at their opposite ends, the opposite ends of said heat transfer tubes being sealed relative to said partitions, exhaust gas inlet means opening into one of said end chambers, exhaust outlet means opening outwardly of the other of said end chambers, means connecting said exhaust system to said exhaust gas inlet means, said central chamber including an upper outlet comprising said steam outlet and an inlet through which water to be heated into steam may be admitted into said central chamber, water supply means operatively associated with said central chamber inlet for supplying water thereto, said water supply means including heating means operative to heat the water supplied thereby, said water supply means including exhaust gas temperature sensing controlled valve means operative to admit additional quantities of heated water into said water and steam compartment means in response to the temperature of the exhaust gas at said outlet end of said exhaust conduit means being elevated to a predetermined level.

2. The combination of claim 1 wherein said central chamber includes a pressure relief valve controlled vent outlet.

3. In combination with an internal combustion engine of the type having an air induction system including primary fuel inlet means and an exhaust system for combustion gases, supplemental fuel inlet means for said induction system including steam generator means having a steam outlet, a gas generator housing having a predetermined amount of iron filings disposed therein and fluid inlet and outlet means, means connecting said steam outlet with said fluid inlet means, and means communicating said fluid outlet means with said supplemental fuel inlet means, said exhaust system including portions which are heated to a high degree as a result of operation of said engine, said heated portions of said exhaust system being in good transfer relation with said gas generator housing for heating the internal surfaces thereof and said iron filings, the passage of steam through said housing and in intimate contact with the heated iron filings in said housing serving to further elevate the temperature of said steam and to produce hydrogen and oxygen gas for passage through said housing outlet and to said supplemental fuel inlet means, said steam generator including a horizontally elongated housing provided with a pair of inner transverse partitions spaced from the opposite ends of said steam generator housing and dividing the latter into opposite end chambers and a central chamber disposed between said partitions, a plurality of elongated horizontal heat transfer tubes extending through said central chamber and opening into said end chambers at their opposite ends, the opposite ends of said heat transfer tubes being sealed relative to said partitions, exhaust gas inlet means opening into one of said end chambers, exhaust outlet means opening outwardly of the other of said end chambers, means connecting said exhaust system to said exhaust gas inlet means, said central chamber including an upper outlet comprising said steam outlet and an inlet through which water to be heated into steam may be admitted into said central chamber, water supply means operatively associated with said central chamber inlet for supplying water thereto, said water supply means



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including heating means operative to heat the water supplied thereby, said water supply means including exhaust gas temperature sensing controlled valve means operative to admit additional quantities of heated water into said water and steam compartment means in re-

sponse to the temperature of the exhaust gas at said outlet end of said exhaust conduit means being elevated to a predetermined level.

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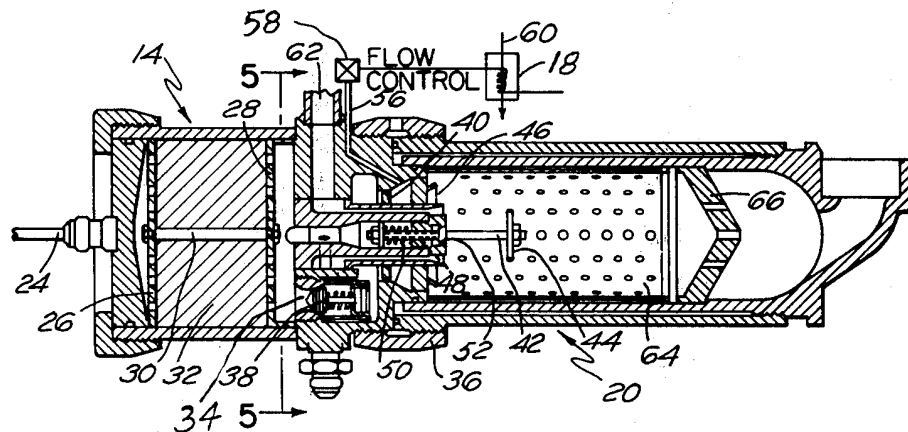
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**United States Patent** [19][11] **4,047,380****Heffernan**[45] **Sept. 13, 1977****[54] COMBUSTION SYSTEM USING DILUTE HYDROGEN PEROXIDE****[75] Inventor:** Robert J. Heffernan, Portsmouth, R.I.**[73] Assignee:** The United States of America as represented by the Secretary of the Navy, Washington, D.C.**[21] Appl. No.:** 675,671**[22] Filed:** Apr. 9, 1976**[51] Int. Cl.<sup>2</sup>** ..... F02C 3/20**[52] U.S. Cl.** ..... 60/39.46 R; 60/39.46 M**[58] Field of Search** ..... 60/39.46 R, 39.46 M, 60/218, 257, 259**[56] References Cited****U.S. PATENT DOCUMENTS**

3,040,521	6/1962	Broughton et al. ....	60/39.46 M
3,091,921	6/1963	Youngquist et al. ....	60/39.46 M
3,135,703	6/1964	Sill .....	60/39.46 M
3,898,794	8/1975	Ariga .....	60/39.46 M

*Primary Examiner*—Carlton R. Croyle*Assistant Examiner*—L. J. Casaregola*Attorney, Agent, or Firm*—Richard S. Sciascia; Arthur A. McGill; Prithvi C. Lall**[57] ABSTRACT**

A combustion system using a dilute hydrogen peroxide ( $H_2O_2$ ) solution as an oxidizer. The system uses the concept of Liquid Phase Extraction and eliminates part of the water produced during the decomposition of hydrogen peroxide into water ( $H_2O$ ) and oxygen ( $O_2$ ). The elimination of a part of the water produced during the decomposition allows the energy resulting from the combustion of oxygen and a fuel to be used to increase the prime mover performance of the system. The system comprises a decomposition chamber, a liquid/gas separator, a heat exchanger and a combustion chamber. Dilute hydrogen peroxide solution is catalytically decomposed in the decomposition chamber. The oxygen and the water produced during the decomposition of  $H_2O_2$  are separated by means of the separator. Some portion of the separated water is extracted. The mixture of oxygen and the remaining water is combined in the combustion chamber with the fuel and is ignited, producing hot gases under high pressure for a prime mover such as a turbine engine.

**8 Claims, 8 Drawing Figures**

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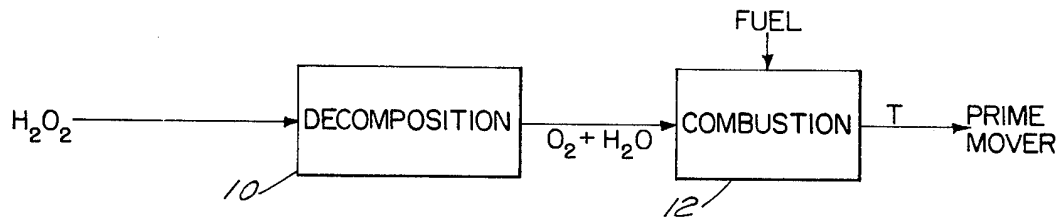


FIG. 1

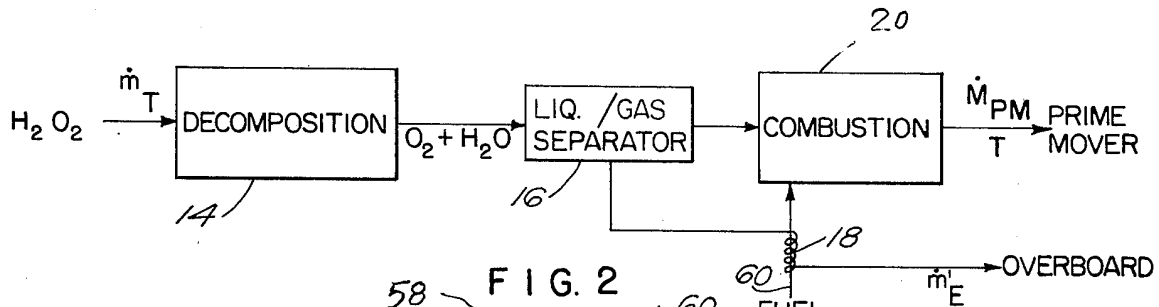


FIG. 2

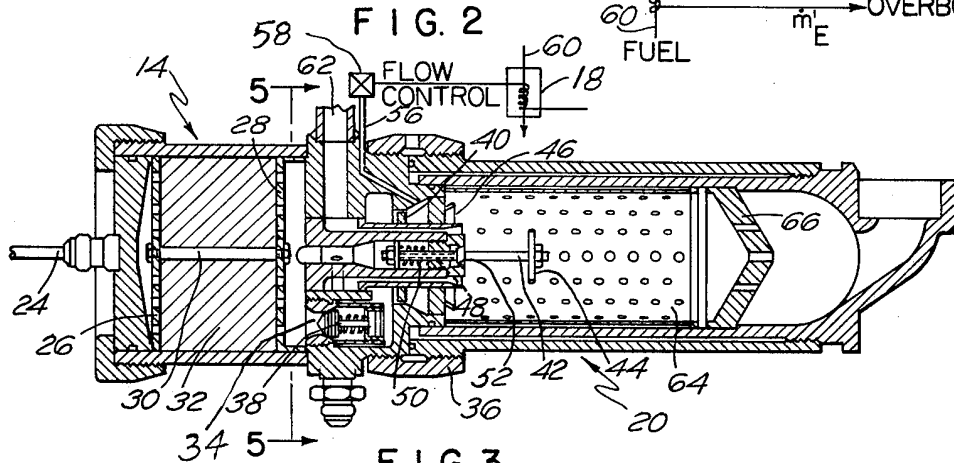


FIG. 3

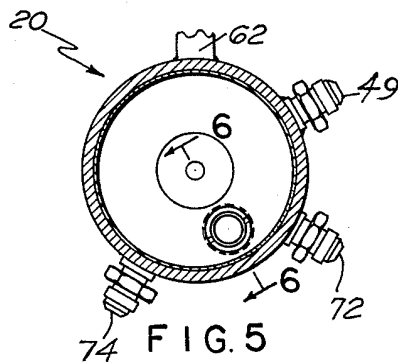


FIG. 5

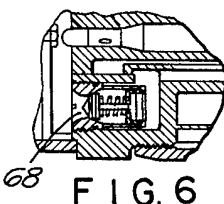


FIG. 6

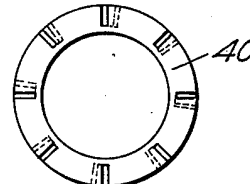


FIG. 4

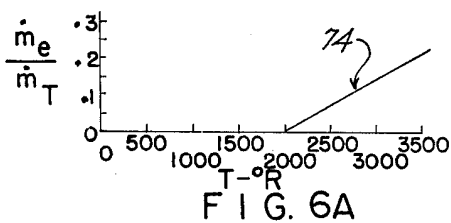


FIG. 6A

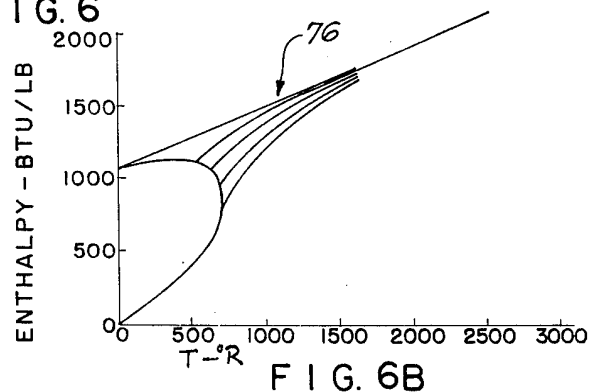


FIG. 6B

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## COMBUSTION SYSTEM USING DILUTE HYDROGEN PEROXIDE

### STATEMENT OF GOVERNMENT INTEREST

The invention described herein maybe manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

### BACKGROUND OF THE INVENTION

This invention relates to a combustion system which uses hydrogen peroxide as a propellant and more particularly to a combustion system which uses dilute solution of hydrogen peroxide and a fuel as a propellant.

Propulsion systems, and particularly those used in underwater applications, have used hydrogen peroxide as a propellant for many years. Although sometimes it is used as a monopropellant, it is often used as an oxygen source, i.e., an oxidizer, in combination with a fuel. In such a conventional system, concentrated hydrogen peroxide ( $H_2O_2$ ) is delivered into a decomposition chamber where it is catalytically decomposed to form oxygen ( $O_2$ ) gas and  $H_2O$ . This process being exothermic results in the generation of heat called "heat of decomposition".  $O_2$  and  $H_2O$  produced then proceed into a combustion chamber where oxygen is combined with a fuel in a stoichiometric ratio. This mixture is then ignited to produce hot gas under pressure which is delivered to a prime mover such as a turbine, piston or a rotary engine. The  $H_2O$  produced during decomposition serves to depress the final combustion temperature and becomes part of the working fluid delivered to the prime mover. The decomposition of high concentrations of  $H_2O_2$  results in the generation of  $O_2$  and  $H_2O$  as a saturated vapor. At lower concentrations (less than 67% or so), however, the quality of  $H_2O$  drops due to the lower heat of decomposition and liquid phase  $H_2O$  is present. Increasing the pressure in the system further increases the percentage of liquid  $H_2O$  present. As an example, decomposition of 40% concentration  $H_2O_2$  at 1400 PSI (pounds per square inch), results in the generation of oxygen ( $O_2$ ) gas and  $H_2O$  and  $H_2O$  so produced being completely in the liquid phase. When the liquid phase  $H_2O$  produced during the decomposition process enters the combustion chamber, it is vaporized and superheated to the equilibrium temperature of the overall combustion process. The heat required to vaporize and superheat the liquid  $H_2O$  is supplied by the energy resulting from the combustion of  $O_2$  and the fuel. This lowers the final temperature of the mixture being delivered to the prime mover and results in lower prime mover performance. It is thus desirable to remove the liquid phase  $H_2O$  produced during the decomposition before the combustion process and thus prevent reduction of performance of the prime mover by increasing the temperature of the hot gas, which in turn improves the overall performance of the prime mover despite the decrease in performance due to decrease, due to  $H_2O$  extraction, in the mass of hot gas delivered to the prime mover.

### SUMMARY OF THE INVENTION

The combustion system using dilute hydrogen peroxide and a fuel as propellant and built according to the teachings of subject invention comprises a decomposition chamber where dilute solution of hydrogen peroxide (40% concentration or less by weight) is catalyti-

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cally decomposed into  $H_2O$  and  $O_2$ . The  $H_2O$  and  $O_2$  so produced in the decomposition chamber are led to a liquid/gas separator which includes a pair of whirl like structures which rotate and separate some of the liquid  $H_2O$  which moves farther from the axis of rotation than  $O_2$ . The separated liquid  $H_2O$  is then extracted and the remaining liquid  $H_2O$  and  $O_2$  are led to the combustion chamber where they are mixed with the fuel. An igniter is ignited in the combustion chamber which produces sufficiently high pressure and temperature before the mixture of  $O_2$ , the remaining  $H_2O$  and the fuel are burnt to produce hot gases under high pressure which are used to propel a prime mover. The extracted  $H_2O$  is circulated in a heat exchanger wherein the incoming fuel is also brought in so as to extract most of the heat from the extracted  $H_2O$  before the fuel is brought into the combustion chamber.

An object of subject invention is to have a combustion system using low concentration hydrogen peroxide and a fuel as propellant for a prime mover such as turbine engine etc.

Another object of subject invention is to have a combustion system using hydrogen peroxide and a fuel as a propellant having increased safety through the use of lower concentrations of hydrogen peroxide while obtaining the performance of the prior art system using higher concentrations of hydrogen peroxide.

Still another object of subject invention is to have a combustion system which extracts a part of liquid  $H_2O$  produced during the decomposition of  $H_2O_2$ .

Still another object of this invention is to have a combustion system which uses a heat exchanger to circulate the extracted  $H_2O$  to raise the temperature of the incoming fuel before feeding it into the combustion chamber of the combustion system for ignition.

Other objects, advantages and novel feature of this invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a block diagram of a combustion system using concentrated  $H_2O_2$  and a fuel as a propellant;

FIG. 2 is a block diagram of a combustion system using low concentration  $H_2O_2$  and a fuel as a propellant;

FIG. 3 is a cross sectional view of a combustion system built according to the teachings of subject invention;

FIG. 4 is a plan view of the separator used in the combustion system of FIG. 3;

FIG. 5 is a cross-section of the combustion system taken along line 5—5 of FIG. 3;

FIG. 6 is a cross-section of the system taken along line 6—6 of FIG. 5;

FIG. 6A is a graphical representation of the ratio of the rate of  $H_2O$  extracted to the rate of production of the components of decomposition mixture when plotted against temperature in the combustion chamber; and

FIG. 6B is a graphical representation of enthalpy of the system when plotted against the temperature in the combustion chamber of the system.

### DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to the drawings wherein like reference characters designate like parts throughout, and more particularly to FIG. 2 thereof a block diagram of a combustion system according to the teachings of sub-

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ject invention is shown. FIG. 1 is a schematic representation of a conventional combustion system wherein a concentrated solution of hydrogen peroxide ( $H_2O_2$ ) is sent into a decomposition chamber 10. The output of decomposition chamber 10 comprising mixture of oxygen ( $O_2$ ) and liquid  $H_2O$  is fed into combustion chamber 12 where the oxygen ( $O_2$ ) is used to ignite the incoming fuel which is used for a prime mover such as a turbine or a piston. For a conventional combustion system using concentrated  $H_2O_2$  (70% or higher  $H_2O_2$  by weight), the amount of heat produced as a result of catalytic decomposition of  $H_2O_2$  raises the  $H_2O$  and  $O_2$  produced to a high temperature. Furthermore, the amount of  $H_2O$  produced during the decomposition of concentrated  $H_2O_2$  is not sufficient enough to lower the temperature of the hot gases resulting from the combustion of the  $O_2$  produced and a fuel to an acceptable operating temperature range of the prime mover. Thus additional water is needed to lower the temperature of the hot gases used for the prime mover to reduce the chance of explosion in the system using concentrated  $H_2O_2$  and a fuel as propellant.

FIG. 2 represents a combustion system built according to the teachings of subject invention wherein hydrogen peroxide in dilute solution, preferably 40%  $H_2O_2$  by weight, is fed into decomposition chamber 14 wherein it is catalytically decomposed, using Argent or its equivalent as a catalytic agent, into its constituents, i.e., ( $O_2$  and  $H_2O$ ). Under the conditions (concentration of  $H_2O_2$  and the pressure) in chamber 14,  $H_2O$  produced is mostly in liquid phase. Furthermore, the temperature of the decomposed components is also not very high. The output of decomposition chamber 14 is then fed into a liquid/gas separator 16 wherein a part of the liquid phase  $H_2O$  is extracted and taken to a heat exchanger 18. The remaining  $H_2O$  and  $O_2$  are then delivered into combustion chamber 20. The extracted water because of high pressure (1400 pounds per square inch) is still in liquid phase and while going through the heat exchanger rejects its heat to the incoming fuel and is piped overboard as shown in FIG. 2. The fuel is then fed into chamber 20 where it is ignited after mixing it with  $O_2$  and the remaining  $H_2O$ . The output of combustion chamber 20 is a mixture of hot gases under high pressure which is used to drive a prime mover such as a turbine engine. As shown in FIG. 6A, the temperature of the oxygen and the remaining  $H_2O$  increase linearly with the ratio of the extracted flow to the total flow (i.e. the rate at which hot gases are delivered to the prime mover). Furthermore, it is known in the prior art that within the operating range of temperature of a combustion system, the output of a prime mover of fixed dimensions and with a fixed fuel supply increases with the increase of temperature of the hot gases delivered to the prime mover. FIG. 6B further illustrates the effect of the  $H_2O$  extraction in the form of a plot between enthalpy of the system (i.e. of the hot gases produced after combustion) and the temperature of the system. FIG. 6B shows that the amount of heat required to change the phase (from liquid phase to vapor phase) of the liquid phase  $H_2O$  without any increase in the temperature of the system is much higher than the amount of heat required to raise the temperature of the system if the liquid phase of  $H_2O$  is eliminated. Consequently, a large amount of heat which would have been required to change the phase of the liquid phase  $H_2O$  which has been eliminated, is used to increase the temperature of the system and thus im-

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prove the performance of the system which is a linear function of its temperature.

As shown in FIG. 3 a dilute solution of hydrogen peroxide, preferably (40%  $H_2O_2$  by weight) is fed into decomposition chamber 14 of the combustion system by means of pipe 24. Hydrogen peroxide entering the decomposition chamber 14 is distributed throughout the entire available space of the decomposition chamber 14 by means of deflection or distribution plate 26 having a plurality of holes therethrough. The decomposition chamber 14 also includes another distribution or deflection plate 28 having a plurality of holes which is held in position together with deflection or distribution plate 26 by shaft 30. Screen 32, preferably made of stainless steel and coated with a catalytic agent such as Argent for decomposing  $H_2O_2$ , inside decomposition chamber 14 is also held in place by means of shaft 30 and deflection or distribution plates 26 and 28. Liquid  $H_2O$  and  $O_2$  produced after decomposition of  $H_2O_2$  inside chamber 14 are allowed to enter area 34 of chamber 36 through passageway 38 as shown in FIG. 3. Phase separator 40 is mounted at one end of shaft 42 which has a flame holder or flame deflector 44 at the other end thereof. Separator 46 is also mounted on shaft 42. Shaft 42 has a hole 48 drilled through the center thereof for the passage of fuel coming via line 60 to inlet 49 and finally to combustion chamber 20. Spring 50 is put under tension due to the pressure of incoming fuel so as to open inlet 52 for allowing fuel into the combustion chamber 20. Outlet line 56 is provided in the combustion chamber to extract some of the liquid phase  $H_2O$  produced during the decomposition of dilute solution of hydrogen peroxide. Line 56 also has a flow control 58 installed which has its output leading to heat exchanger 18 where  $H_2O$  loses most of its heat to the incoming fuel through line 60. A conventional igniter is brought via inlet 62 into the combustion chamber 20 to ignite and to bring the temperature and pressure inside the combustion chamber 20 to the point of bringing about effective combustion. Combustion chamber 20 has an inner liner 64 to cause some turbulence in the mixture of  $O_2$ ,  $H_2O$  and the fuel in order to mix the fuel with oxygen gas. Restrictor 66 is used to further enhance the combustion reaction before the hot gases produced during combustion of  $O_2$  and the fuel are delivered through a nozzle to a prime mover such as a turbine. FIG. 4 is a plan view of phase separator 40 which is a whirl like structure mounted on shaft 42. Another similar whirl like structure 46 is also mounted on shaft 42. When fixed separators 40 and 46 rotate the fluid about an axis through shaft 42, they move liquid phase  $H_2O$  farther away from the axis leaving  $O_2$  gas closer to the axis. Part of the separated  $H_2O$  is extracted through outlet line 56. FIG. 5 is cross section of FIG. 3 taken along line 5—5 wherein inlet 72 is provided to keep the combustion chamber cool by circulating water therethrough and fitting 74 is used for the system start-up using some auxiliary means such as pressurized air. FIG. 6 is a cross section of FIG. 5 taken along line 6—6 wherein a conventional check valve 68 is shown to control the flow of  $O_2$  and the  $H_2O$  produced during the decomposition of dilute  $H_2O_2$  into the combustion chamber 20.

As pointed out above, FIG. 6A is graphical representation of the relationship between the ratio of the rate of extraction of  $H_2O$  produced during the decomposition of dilute  $H_2O_2$  and rate of production of the total mass of hot gases produced and the temperature of the system (i.e. hot gases in the combustion chamber). Straight line

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74 indicates that the temperature of the combustion system increases as the ratio of the extracted flow to the total flow increases, which in turn changes the efficiency of the combustion system. FIG. 6B shows graphically a relationship between enthalpy and the temperature of the system (i.e. hot gases produced in the combustion chamber). Line 76 indicates that the heat provided to the system in vapor phase goes to increase the temperature of the system and thereby increases its efficiency. However, other curves plotted at various pressures indicate that a large amount of heat provided is used up to change the phase of H<sub>2</sub>O present from liquid phase to vapor phase without changing the temperature of the system. Thus a large amount of heat energy is used for this purpose which would be made available to raise the temperature of the system if most of the liquid phase H<sub>2</sub>O is removed therefrom.

Thus a combustion system of the present invention comprises a decomposition chamber which is used to decompose dilute H<sub>2</sub>O<sub>2</sub> into its components, i.e., liquid H<sub>2</sub>O and O<sub>2</sub>. Liquid H<sub>2</sub>O and O<sub>2</sub>, so produced is separated by using a separator and some of liquid H<sub>2</sub>O is extracted before delivering the remaining H<sub>2</sub>O and O<sub>2</sub> into the combustion chamber where they are mixed with a fuel before starting their combustion reaction. The hot gases under pressure produced in the combustion chamber are then delivered through a nozzle to a prime mover such as a turbine or the piston of an engine.

Obviously many modification and variations of the present invention are possible in the light of the above teachings. As an example a catalytic agent for the decomposition of H<sub>2</sub>O<sub>2</sub> can be something other than Argent. Furthermore, the separator means for extracting liquid H<sub>2</sub>O from the components of decomposed H<sub>2</sub>O<sub>2</sub> can vary in design. It is therefore understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

I claim:

1. A combustion system using dilute hydrogen peroxide having a concentration less than 40 percent by weight and a fuel propellant which comprises:

a decomposition chamber for catalytically decomposing the dilute hydrogen peroxide having a concentration less than 40 percent by weight into liquid

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phase water and vapor phase oxygen as the decomposed components thereof;

a liquid/gas separator means for separating the liquid phase water and vapor phase oxygen of the decomposed dilute hydrogen peroxide, said separator means being mounted adjacent said decomposition chamber and being connected to said decomposition chamber;

means for feeding the components of the decomposed dilute hydrogen peroxide from said decomposition chamber into said liquid/gas separator means;

means for extracting a portion of the liquid phase water from the components of the decomposed dilute hydrogen peroxide being fed to said separator means; and

a combustion chamber for mixing the oxygen and the remaining water with the fuel and for igniting the mixture thereof, said combustion chamber being mounted adjacent said separator means and being connected to said separator means.

2. The combustion system of claim 1 wherein said decomposition chamber includes a pair of distribution plates being held in position by a shaft and having a screen being connected between said pair of distribution plates.

3. The combustion system of claim 2 wherein said screen of said decomposition chamber includes a catalytic agent for decomposing the dilute hydrogen peroxide coated thereon.

4. The combustion system of claim 3 wherein said separator means comprises two whirl like structures.

5. The combustion system of claim 4 wherein said means for feeding the components of the decomposed dilute hydrogen peroxide includes a check valve therein for preventing explosive mixture from said combustion chamber from entering said decomposition chamber.

6. The combustion system of claim 5 wherein said combustion chamber further includes means for raising pressure and temperature inside said combustion chamber to increase the combustion process inside said combustion chamber.

7. The combustion system of claim 6 wherein said combustion chamber further includes a one way valve means for bringing the fuel into said chamber.

8. The combustion system of claim 7 wherein said one way valve means includes a spring being put under tension due to the pressure of the fuel so as to permit entrance of the fuel inside said combustion chamber.

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**United States Patent** [19]**Yamane et al.**[11] **4,079,703**[45] **Mar. 21, 1978**

[54] **INTERNAL COMBUSTION ENGINE  
OPERATED ON INJECTED FUEL  
SUPPLEMENTED WITH HYDROGEN**

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Morita, Tokyo; Zene Ueno, Fuchu,**  
all of Japan

[73] Assignee: **Nissan Motor Company, Ltd., Japan**

[21] Appl. No.: **641,759**

[22] Filed: **Dec. 17, 1975**

[30] **Foreign Application Priority Data**

Dec. 18, 1974 Japan ..... 49-145190

[51] Int. Cl.<sup>2</sup> ..... **F02B 43/08**

[52] U.S. Cl. .... **123/3; 123/32 SP;  
123/DIG. 12**

[58] Field of Search ..... **123/3, 1 A, DIG. 12,  
123/32 ST, 32 SP, 32 SA**

[56]

**References Cited****U.S. PATENT DOCUMENTS**

2,882,873	4/1959	Witzky .....	123/32 ST
3,015,326	1/1962	Wirsching et al. ....	123/140 CC
3,195,520	7/1965	Simko .....	123/32 ST
3,336,912	8/1967	Morris .....	123/140 CC
3,696,795	10/1972	Smith et al. ....	123/DIG. 12
3,717,129	2/1973	Fox .....	123/3
3,855,980	12/1974	Weisz et al. ....	123/3
3,939,806	2/1976	Bradley .....	123/3
3,948,224	4/1976	Knapp et al. ....	123/3
3,968,775	7/1976	Harpman .....	123/3
3,970,054	7/1976	Henault et al. ....	123/DIG. 12

*Primary Examiner*—Charles J. Myhre

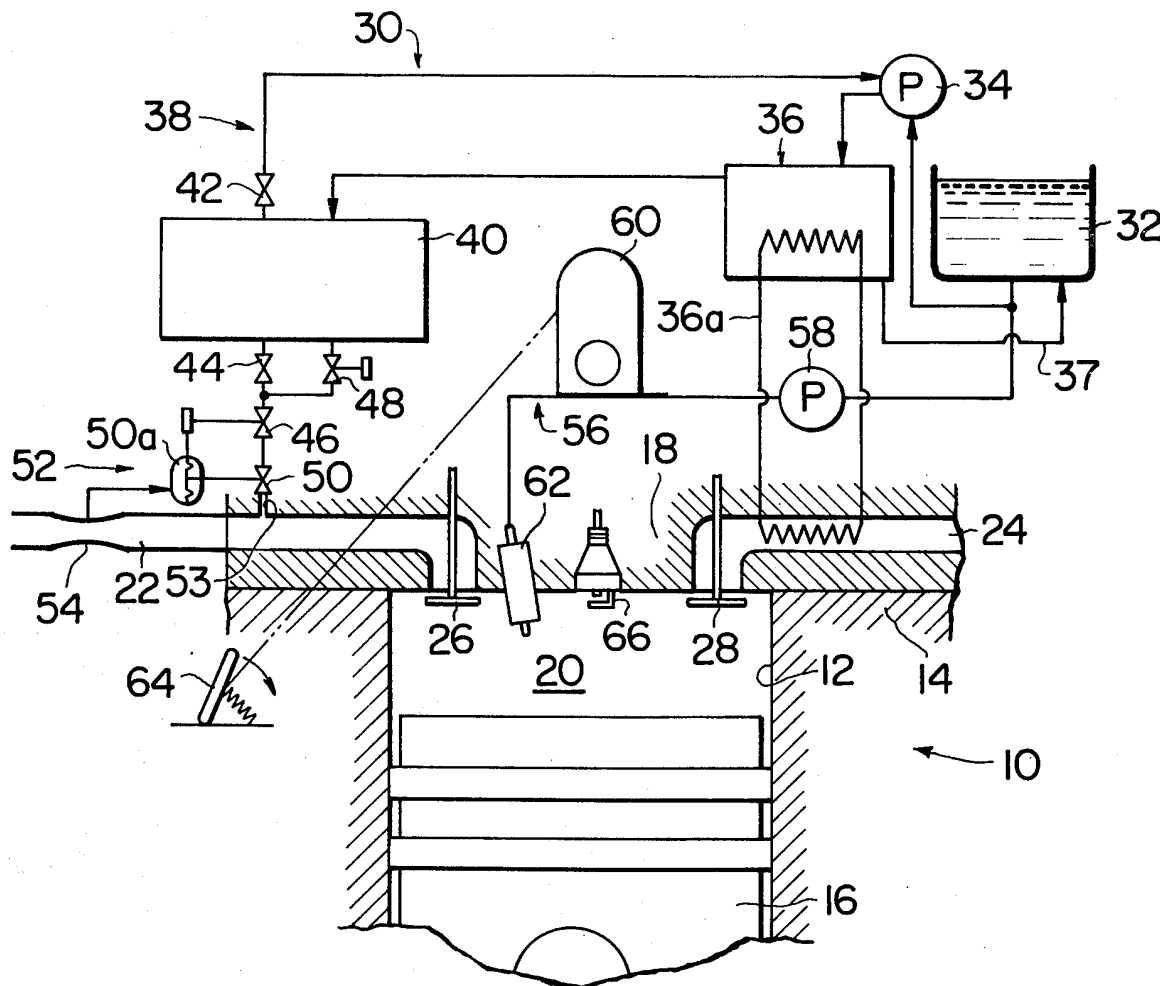
*Assistant Examiner*—David D. Reynolds

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**ABSTRACT**

A lean mixture, rich in hydrogen, is introduced into the combustion chamber. Fuel is then injected to the center of the chamber to provide a rich strata. The rapid flame front propagation due to the hydrogen minimizes the HC production quench.

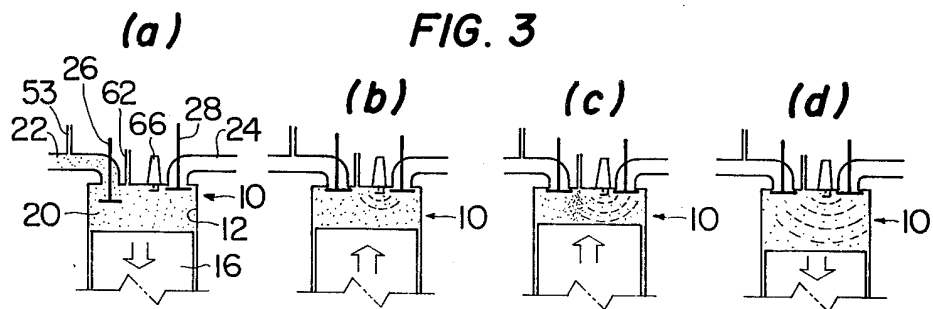
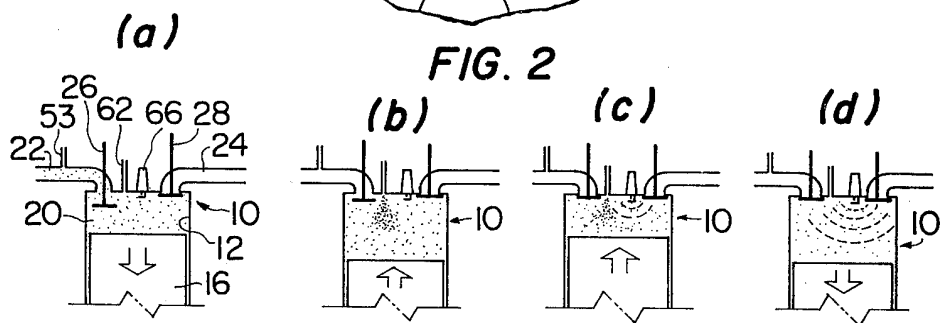
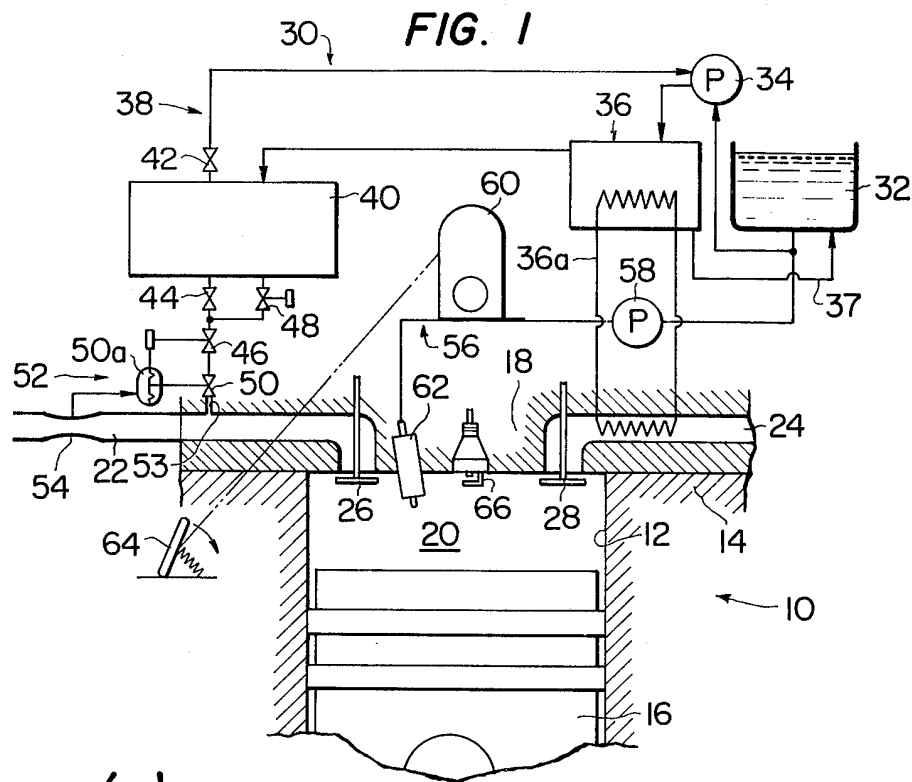
**12 Claims, 3 Drawing Figures**



U.S. Patent

March 21, 1978

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## INTERNAL COMBUSTION ENGINE OPERATED ON INJECTED FUEL SUPPLEMENTED WITH HYDROGEN

This invention relates to an internal combustion engine operated on an air-fuel mixture supplemented with hydrogen gas.

It is an object of the present invention to provide an improved internal combustion engine which enables stable operation of the engine with lower emission level of noxious gases.

Another object of the present invention is to provide an improved spark ignition internal combustion engine by which combustion chambers are firstly supplied with a mixture of hydrogen gas and air and thereafter liquid fuel is injected to the generally central portion of each combustion chamber, whereby the air-fuel mixture within the combustion chamber is stratified to effectively be burned to lower the emission levels of carbon monoxide and unburned hydrocarbons.

Other objects and features of the improved internal combustion engine in accordance with the principle of the present invention will become more apparent from the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematical representation of a preferred embodiment of an internal combustion engine in accordance with the principle of the present invention;

FIG. 2 is schematical representation showing a manner of operating the engine of FIG. 1; and

FIG. 3 is schematical representation similar to FIG. 2, but shows another manner of operating the engine of FIG. 1.

Referring now to FIG. 1, there is shown a preferred embodiment in accordance with the principle of the present invention in which a spark-ignition internal combustion engine of the four-cycle valve-in-head type is designated by reference numeral 10. The engine 10 is a multi-cylinder internal combustion engine, only one cylinder 12 of which is shown in the vertical transverse section. The cylinder 12 is formed in the body casting portion of the cylinder block 14. A piston 16 is reciprocally disposed in the cylinder 12 and is operatively connected by a connecting rod to a crank arm of a crankshaft (they are not shown).

Covering the upper portion of the cylinder 12 is a cylinder head structure 18 which is secured to the body casting portion of the cylinder block 14 by bolts (not shown). The cylinder head 18 cooperates with the upper portion of the piston 16 to form a combustion chamber 20 therebetween. The cylinder head 18 is formed with an air-intake passage 22 and an exhaust passage 24 which are connected to the combustion chamber 20 through an intake valve 26 and an exhaust valve 28, respectively. The air-intake passage 22 is arranged to supply atmospheric air therethrough to the combustion chamber 20.

As seen, the internal combustion engine 10 is equipped with a hydrogen gas supply means 30 which comprises a fuel tank 32 containing liquid fuel therein or a fuel source. The fuel tank 32 is connected to a fuel pump 34 for admitting the fuel from the fuel tank 32 into a fuel reforming device 36 which forms part of hydrogen gas source 38. The reforming device 36 is arranged to generate reformed gas containing hydrogen gas by endothermic reforming reaction. The reforming device 36 is equipped with a heater 36a or a heat exchanger for

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supplying the heat for the endothermic reforming reaction carried out in the reforming device 36. The heat 36a is arranged to be supplied with the heat of the exhaust gases emitted from the combustion chamber 20. A pipe 37 connecting the reforming device 36 and the fuel tank 32 functions to return the liquid fuel still not reformed to the fuel tank 32. The reforming device 36 is connected to a reformed gas accumulator 40 for accumulating the reformed gas admitted from the reforming device. The accumulator 40 has a pressure responsive switch 42 which is arranged to stop the function of the fuel pump 34 when the pressure within the accumulator 40 exceeds a predetermined level. The accumulator 40 is connected through a check valve 44 to a normally open valve 46 which is arranged to be closed when the engine 10 is stopped. The accumulator 40 is further connected to an upstream portion of the valve 46 through a normally closed valve 48 which is arranged to open for allowing the reformed gas to flow during engine starting. The valve 46 is connected to a diaphragm actuating valve 50 which forms part of regulating means 52. The valve 50 is connected to a nozzle 53 or a hydrogen gas supply nozzle which opens into the air-intake passage 22 in order to supply the reformed gas to the stream of air flowing through the air-intake passage 22. The diaphragm assembly 50a of the valve 50 is communicated with a venturi portion 54 of the air-intake passage 22 and therefore the valve 50 is arranged to regulate the amount of the reformed gas supplied through the nozzle 53 in response to the vacuum generated at the venturi portion 54, in other words, the air amount supplied to the combustion chamber 20 through the air-intake passage 22.

The internal combustion engine 10 is equipped with fuel injecting means 56 comprising the fuel tank 32 containing the liquid fuel. The fuel tank 32 is connected to a fuel pump 58 which is in turn connected to a variable plunger pump 60. The variable plunger pump 60 is arranged to supply the combustion chamber 20 with variable amounts of the liquid fuel through a fuel injector 62 in response to the movement of the accelerator 64. The fuel injector 62 is disposed through the generally central portion of the cylinder head 18 and extends into the combustion chamber 20. The injector 62 is oriented generally toward the central portion of the combustion chamber 20 to inject the liquid fuel admitted from the plunger pump 60 toward same. Disposed adjacent to the fuel injector 62 and through the generally central portion of the cylinder head 18 is a spark plug 66 or an igniter which functions to ignite a relatively rich air-fuel mixture formed at the central portion of the combustion chamber 20 by mixing the liquid fuel sprayed from the injector 62 with the air inducted through the air-intake passage 22.

With the arrangement mentioned hereinbefore, when the engine 10 is started, the reformed gas containing hydrogen gas within the accumulator 40 is supplied from the nozzle 52 into the air-intake passage 22 through the valves 46, 48 and 50. Then, the supplied reformed gas is mixed with the air passing through the air-intake passage 22, in which the mixed gas is set at a lean air-fuel (reformed gas) mixture. After engine starting or during normal engine operation, the heat exchanger 36a works receiving heat from the exhaust gases to operate the fuel reforming device 36. The reforming device 36 then generates the reformed gas and the reformed gas is admitted to the accumulator 40. The reformed gas is thereafter supplied through the valves

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44, 46 and 50 from the nozzle 52 into the air-intake passage 22 to mix with the air passing through the air-intake passage 22.

FIG. 2 illustrates a manner of operation of the engine 10 constructed in accordance with the present invention, at position (a) of which the mixed gas of reformed gas and air in the air-intake passage 22 is thereafter sucked and supplied through the intake valve 26 into the combustion chamber 20 by descent of the piston 16 or during suction or induction stroke of the engine 10. At position (b), the liquid fuel is injected or sprayed from the injector 62 to the generally central portion of the combustion chamber 20 during the compression stroke. In this state, the relatively rich air-fuel mixture containing hydrogen gas is formed at the generally central portion of the combustion chamber 20 and a layer of relatively lean air-fuel mixture containing hydrogen gas is formed around the rich air-fuel mixture. At position (c), the mixture compressed by the piston 16 is then ignited by the spark plug 66, in which the spark plug 66 ignites the rich air-fuel mixture at the central portion of the combustion chamber 20 to secure the ignition of the entire air-fuel mixture. At position (d), combustion spreads to the layer of lean air-fuel mixture surrounding the rich air-fuel mixture and then the gas within the combustion chamber expands to cause the piston to descend. It should be noted that the layer of the mixed gas containing hydrogen gas is adjacent the inner wall of the combustion chamber 20 and accordingly the layer is effectively combusted through the layer is of the lean air-fuel mixture. This prevents imperfect combustion of the lean mixture adjacent the inner wall surface of the combustion chamber due to the low calorific value of the lean mixture and release or absorption of heat generated by the combustion through the wall of the combustion chamber. Therefore formation of the mixture layer containing hydrogen gas at the portion adjacent the inner wall of the combustion chamber noticeably contributes to lowering emission levels of carbon monoxide and unburned hydrocarbons.

FIG. 3 illustrates another manner of operation of the engine 10 which is similar to that of FIG. 2 with the exception that the liquid fuel is injected from the fuel injector 62 after the mixed gas of reformed gas and air is ignited by the spark plug 66. As shown at position (b), the mixed gas containing hydrogen gas is ignited at a timing before top dead center. The ignition timing is preferably about 10° before top dead center. At position (c), the liquid fuel is injected and sprayed into the combustion chamber 20 to be ignited with the flame produced by the combustion of the mixed gas.

While the fuel reforming device 36 and its accessories are shown and described as a hydrogen gas source, it will be seen that a cylinder containing hydrogen gas may be used for the same purpose.

It will be understood that the engine according to the present invention is, through not shown, equipped with means for setting the spark-ignition timing of the spark-plug 66 after the fuel injection timing of the injector 62 when operated in the manner shown in FIG. 2, whereas with means for setting the timing of the spark-plug 66 before the timing of the injector 62 when operated in the manner shown in FIG. 3.

As is apparent from the foregoing discussion, with the internal combustion engine in accordance with the present invention, the stratified charge of the air-fuel mixture is achieved and therefore ignition and combustion of the air-fuel mixture are effectively carried out

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even if the air-fuel mixture is as a whole over lean, and thermal efficiency of the engine is as a matter of course improved. In addition, since the air-fuel mixture adjacent the inner wall surface of the combustion chamber contains hydrogen gas, the air-fuel mixture is effectively burned to prevent the incomplete combustion and accordingly the emission levels of carbon monoxide and unburned hydrocarbons are lowered to a considerable extent.

What is claimed is:

1. A method of operating an internal combustion engine having a combustion chamber, comprising the steps in the following order of:

supplying a mixture of air and hydrogen gas into the combustion chamber;  
igniting the mixture in the combustion chamber; and  
supplying a sprayed liquid fuel into the combustion chamber to be burned with the mixture.

2. A method as claimed in claim 1, in which the step of supplying a mixture includes a step of supplying the hydrogen gas into the stream of the air directed into the combustion chamber.

3. A method as claimed in claim 1, in which the step of supplying a sprayed fuel is included a step of injecting the fuel directly into the combustion chamber.

4. A method as claimed in claim 2, in which the step of supplying the hydrogen gas includes a step of regulating the supply amount of hydrogen gas in response to the air amount directed to the combustion chamber.

5. An internal combustion engine having a cylinder, a cylinder head and a piston reciprocally disposed in the cylinder to define a combustion chamber between the cylinder head, comprising:

an air-intake passage fluidly connected to the combustion chamber to supply air therethrough to the combustion chamber;

hydrogen gas supply means for supplying hydrogen gas into said air-intake passage in response to the amount of the air supplied to the combustion chamber, said hydrogen gas supply means including

a hydrogen gas source, said hydrogen gas source including a fuel source containing a liquid fuel therein, a fuel pump connected to said fuel source, a fuel reforming device connected to said fuel pump and arranged to generate the reformed gas containing hydrogen gas, a reformed gas accumulator connected to said reforming device for accumulating the reformed gas admitted from the reforming device, a pressure responsive switch arranged to stop the function of said fuel pump when the pressure within the accumulator exceeds a predetermined level, a check valve connected to the accumulator, a normally open valve connected to said check valve and arranged to close for blocking the reformed gas to flow when the engine is stopped, and a normally closed valve connecting the accumulator and the upstream portion of said normally open valve, and arranged to open for allowing the reformed gas to flow during engine starting,

regulating means connected to said hydrogen gas source for regulating the hydrogen gas flowing amount in response to the air amount supplied to the combustion chamber, and

a hydrogen gas supply nozzle connected to said regulating means and opening into said air-intake passage;

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fuel injecting means for injecting liquid fuel to the central portion of the combustion chamber to form a rich air-fuel mixture at the generally central portion of the combustion chamber; and

an igniter disposed through the generally central portion of the cylinder head to ignite the rich air-fuel mixture at the generally central portion of the combustion chamber.

6. An internal combustion engine as claimed in claim 5, in which said regulating means includes a venturi portion formed at said air-intake passage, and a diaphragm actuating valve connected to said normally open valve and arranged to open for allowing the reformed gas to flow in response to the vacuum generated at said venturi portion, said diaphragm actuating valve being connected to said hydrogen gas supply nozzle.

7. An internal combustion engine as claimed in claim 5, in which said fuel reforming device is equipped with a heater for supplying the heat for endothermic reforming reaction carried out in the reforming device, said heater being arranged to be supplied with heat of the exhaust gas emitted from the combustion chamber.

8. An internal combustion engine as claimed in claim 5, in which said hydrogen gas source includes a cylinder containing hydrogen gas.

9. An internal combustion engine as claimed in claim 5, in which said fuel injecting means includes a fuel source containing a liquid fuel therein, a fuel pump connected to said fuel source, a fuel injector disposed through the generally central portion of the cylinder head, said fuel injector being oriented to the generally central portion of the combustion chamber, and a variable plunger pump connecting said fuel pump and said fuel injector and arranged to supply the combustion chamber with a variable amount of the liquid fuel through said fuel injector in response to the movement of an accelerator.

10. An internal combustion engine having a cylinder, a cylinder head and a piston reciprocally disposed in the cylinder to define a combustion chamber between the cylinder head, comprising:

an air-intake passage fluidly connected to the combustion chamber to supply air therethrough to the combustion chamber;

hydrogen gas supply means for supplying hydrogen gas into said air-intake passage in response to the amount of the air supplied to the combustion chamber, said hydrogen gas supply means including a hydrogen gas source, said hydrogen gas source including a fuel source containing a liquid fuel therein, a fuel pump connected to said fuel source, a fuel reforming device connected to said fuel pump and arranged to generate the reformed gas containing hydrogen gas, said fuel reforming device being equipped with a heater for supplying the heat for endothermic reforming reaction carried out in the reforming device, said heater being ar-

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ranged to be supplied with heat of the exhaust gas emitted from the combustion chamber, a reformed gas accumulator connected to said reforming device for accumulating the reformed gas admitted from the reforming device, a pressure responsive switch arranged to stop the function of said fuel pump when the pressure within the accumulator exceeds a predetermined level, a check valve connected to the accumulator, a normally open valve connected to said check valve and arranged to close for blocking the reformed gas to flow when the engine is stopped, and a normally closed valve connecting the accumulator and the upstream portion of said normally open valve, and arranged to open for allowing the reformed gas to flow during engine starting, regulating means connected to said hydrogen gas source for regulating the hydrogen gas flowing amount in response to the air amount supplied to the combustion chamber, said regulating means including a venturi portion formed at said air-intake passage, and a diaphragm actuating valve connected to said normally open valve and arranged to open for allowing the reformed gas to flow in response to the vacuum generated at said venturi portion, said diaphragm actuating valve being connected to said hydrogen gas supply nozzle, and a hydrogen gas supply nozzle connected to said regulating means and opening into said air-intake passage;

fuel injecting means for injecting liquid fuel to the central portion of the combustion chamber to form a rich air-fuel mixture at the generally central portion of the combustion chamber, said fuel injecting means including a fuel source containing a liquid fuel therein, a fuel pump connected to said fuel source, a fuel injector disposed through the generally central portion of the cylinder head, said fuel injector being oriented to the generally central portion of the combustion chamber, and a variable plunger pump connecting said fuel pump and said fuel injector and arranged to supply the combustion chamber with a variable amount of the liquid fuel through said fuel injector in response to the movement of an accelerator; and

an igniter disposed through the generally central portion of the cylinder head to ignite the rich air-fuel mixture at the generally central portion of the combustion chamber.

11. An internal combustion engine as claimed in claim 10, in which further comprising means for setting the ignition timing of said igniter before the fuel injection timing of said fuel injecting means.

12. An internal combustion engine as claimed in claim 10, in which further comprising means for setting the ignition timing of said igniter after the fuel injection timing of said fuel injecting means.

\* \* \* \* \*

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**United States Patent** [19][11] **4,081,656****Brown**[45] **Mar. 28, 1978**[54] **ARC-ASSISTED OXY/HYDROGEN  
WELDING**[76] Inventor: **Yull Brown**, 182 Auburn Rd.,  
Auburn, New South Wales,  
Australia[21] Appl. No.: **722,125**[22] Filed: **Sep. 10, 1976****Related U.S. Application Data**[62] Division of Ser. No. 489,921, Jul. 19, 1974, Pat. No.  
4,014,777.[30] **Foreign Application Priority Data**

Jul. 20, 1973	Australia .....	PB4159
Aug. 3, 1973	Australia .....	PB4341
May 2, 1974	Australia .....	PB7418

[51] Int. Cl.<sup>2</sup> ..... **B23K 17/00; C25B 15/02;**  
C25B 1/04[52] U.S. Cl. .... **219/137.31; 219/75;**  
219/121 P; 228/242; 431/2; 431/11[58] Field of Search ..... 228/242; 219/75, 121 P,  
219/137 R; 431/2, 11; 204/129

[56]

**References Cited****U.S. PATENT DOCUMENTS**

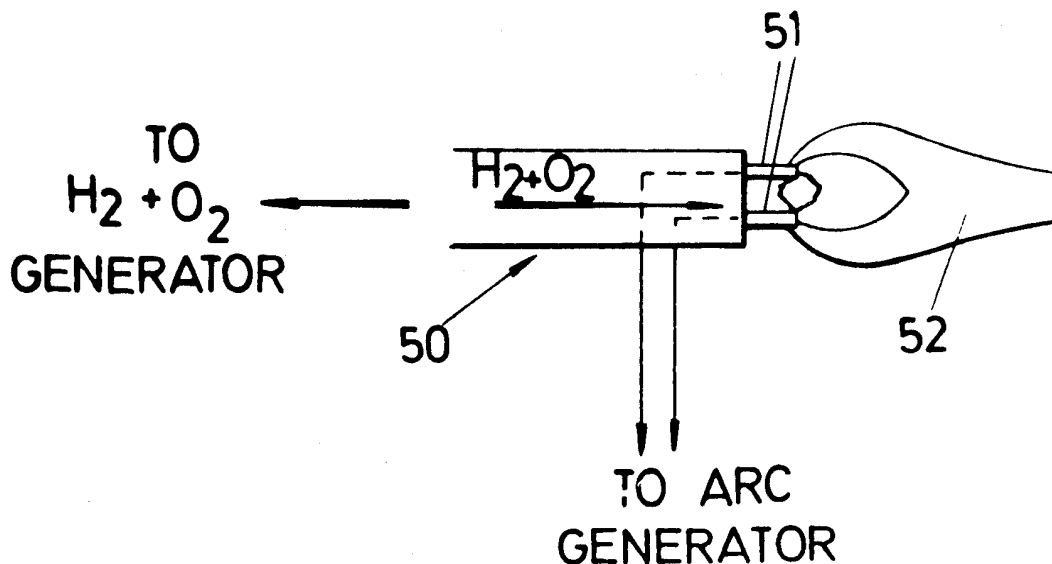
1,037,979	9/1912	Perkins .....	219/75 X
2,874,265	2/1959	Reed et al. ....	219/75 X
2,900,485	8/1959	Clark .....	219/75
3,045,665	7/1962	Moyat .....	204/129 X
3,262,872	7/1966	Rhodes et al. ....	204/129 X
3,310,483	3/1967	Rhodes .....	204/129 X

*Primary Examiner*—Donald G. Kelly*Assistant Examiner*—K. J. Ramsey*Attorney, Agent, or Firm*—Hill, Gross, Simpson, Van  
Santen, Steadman, Chiara & Simpson

[57]

**ABSTRACT**

This invention relates to welding, brazing or the like utilizing a mixture of hydrogen and oxygen generated in substantially stoichiometric proportions in an electrolytic cell by electrical dissociation of water, the mixture so generated being passed from the generator through a flashback arrestor and thence to a burner where the gases are ignited. The invention also relates to atomic welding in which the above mentioned mixture is passed through an arc causing dissociation of both the hydrogen and oxygen into atomic hydrogen and oxygen which on recombination generate an intensely hot flame.

**17 Claims, 7 Drawing Figures**

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FIG. 1.

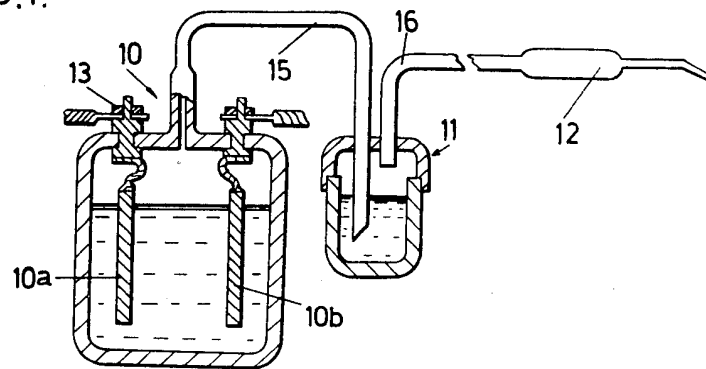
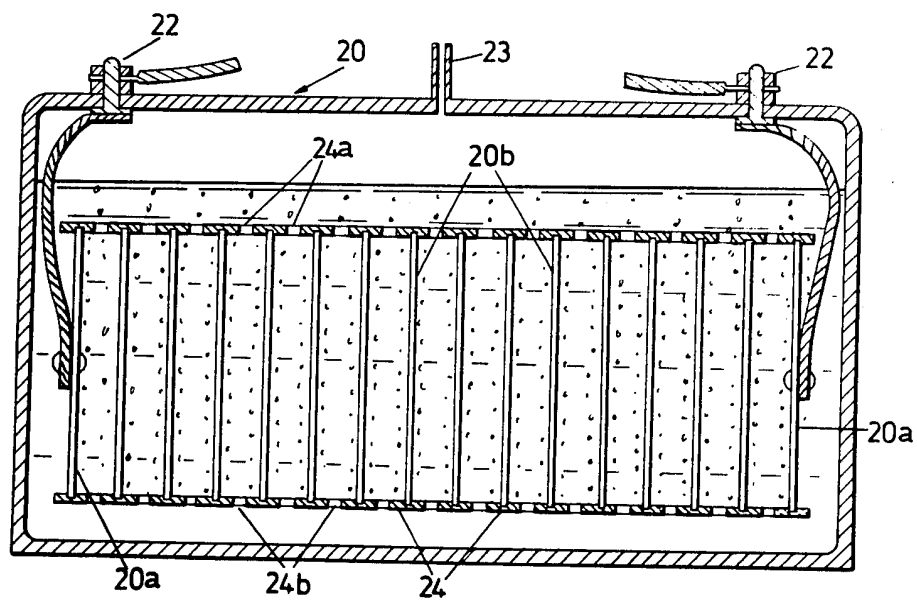


FIG. 2.



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FIG. 3.

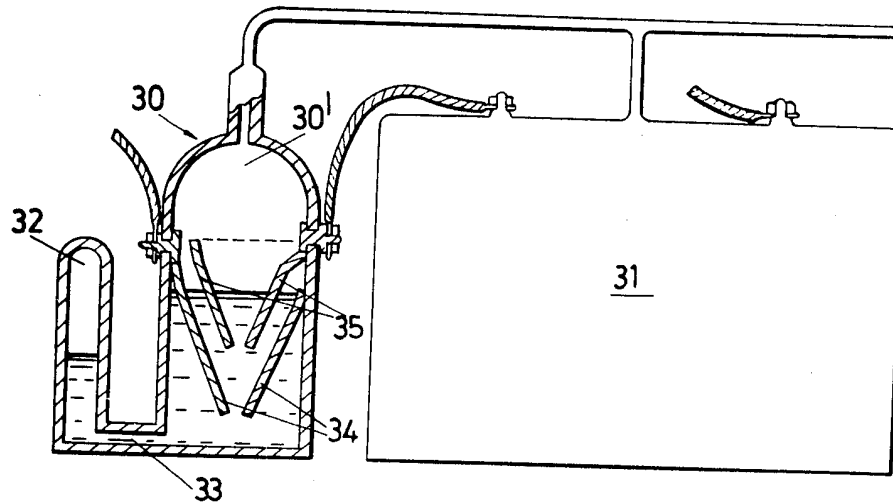
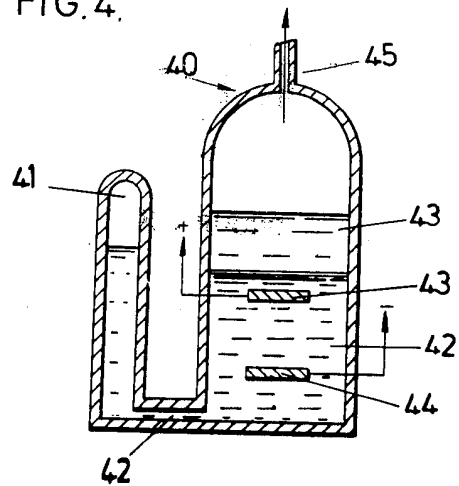


FIG. 4.



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FIG. 5.

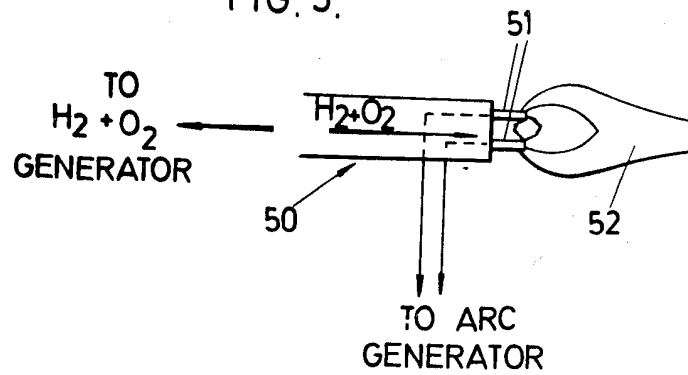
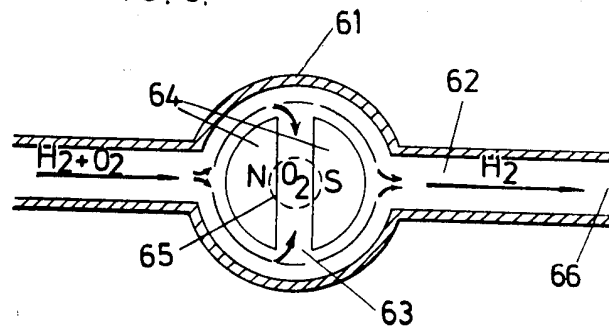


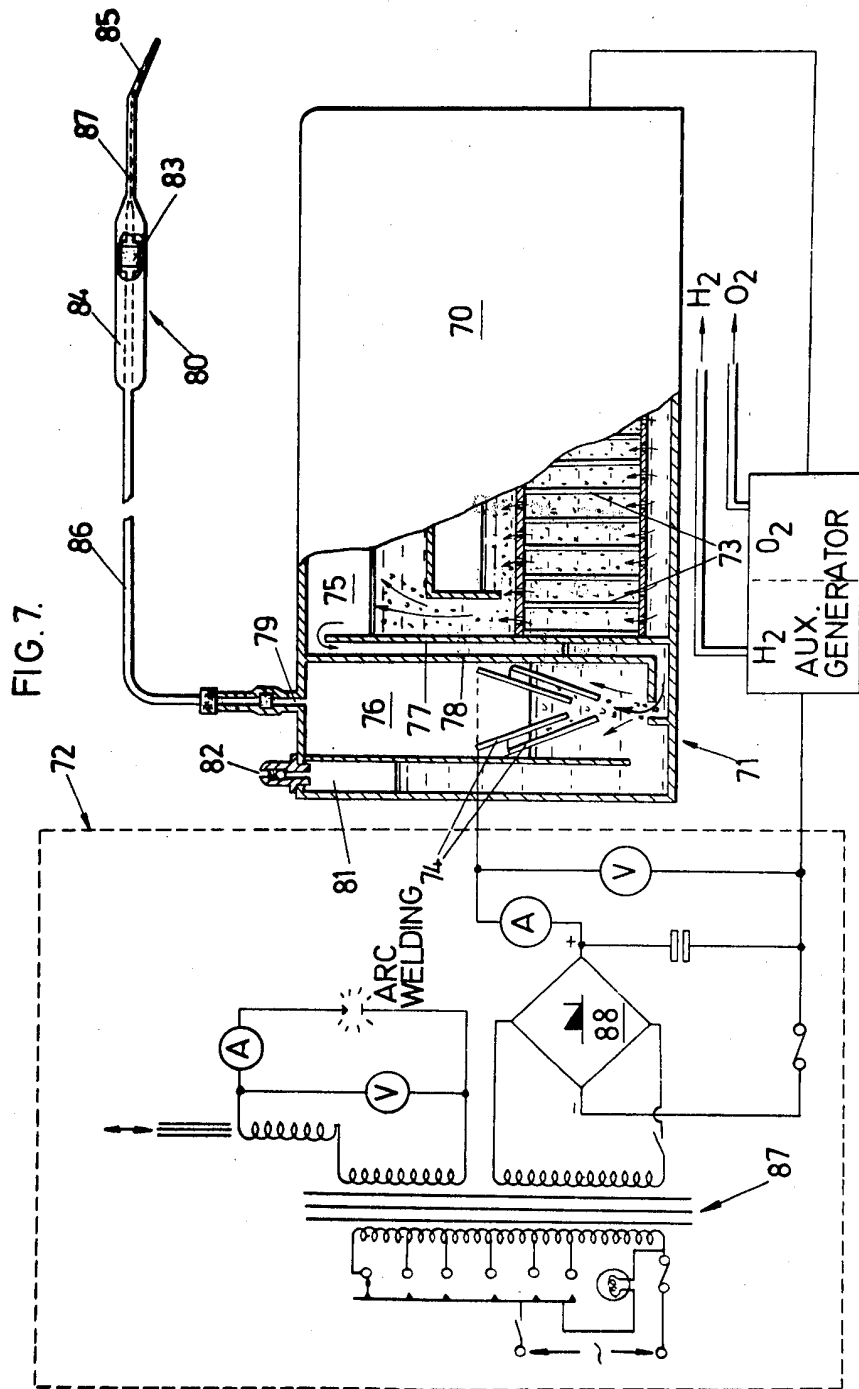
FIG. 6.



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**ARC-ASSISTED OXY/HYDROGEN WELDING**

This is a division of application Ser. No. 489,921 filed July 19, 1974, now U.S. Pat. No. 4,014,777.

This invention relates to welding, brazing and the like, utilising hydrogen and oxygen, and extends to such applications as oxy-welding, oxy-cutting, atomic welding, and welding or cutting in combination with electric arc techniques. The invention also provides for the generation of hydrogen and oxygen for the abovementioned applications in combination therewith or separately.

A most important application of the invention is atomic welding utilising the properties of atomic oxygen in combination with atomic hydrogen (for welding) or atomic oxygen separately (for cutting). This particular application of the invention is based, among other things, on the appreciation that considerable energy is associated with the dissociation of molecular oxygen into atomic oxygen by passing this gas through an arc, and that this property can be usefully employed to generate temperatures even higher than those previously attainable with, for example, an atomic hydrogen flame. The significance of the energy which can be obtained in this way can be appreciated from the following reactions that take place, and the heat energies associated therewith, when hydrogen and oxygen are both passed through an electric arc. Thus:

$H_2 \rightarrow H + H$	absorbing 101,000 cal. per gram mole
$O_2 \rightarrow O + O$	absorbing 117,000 cal. per gram mole
	total 218,000 cal. per gram mole

On recombination of these atoms this energy is released as heat through a number of complex chemical reactions and results in an extremely high flame temperature. Previously it would not have been considered possible to practically pass oxygen or a mixture of oxygen and hydrogen together through an arc due to the highly explosive or inflammable nature of such gases. However in accordance with the concepts of the present invention this is indeed both possible and practical and, as mentioned above, enables the realisation of much higher welding or cutting temperatures than hitherto obtainable by known practical means.

One of the objects of the present invention is to provide a method and apparatus whereby hydrogen and oxygen can be generated quickly and conveniently for immediate use for welding, etc., without many of the disadvantages associated with conventional gas welding practice. For example, the practice of employing cylinders (or "bottles") of gas, usually oxygen and acetylene can have significant disadvantages, particularly for users working remote from a supply depot and for whom there might be an appreciable delay between the placing of an order for a delivery of gas the the actual delivery. For such users, in order to ensure an adequate supply of gas when a particular job demands it, it is often necessary to order fresh supplies in advance, even before the supply on hand is fully used, or else risk running out of gas before a job is completed. Since bottles of gas are generally delivered on a strictly exchange basis — in that a used bottle must be returned in exchange for a refilled bottle — the practice can mean a significant waste, as far as the user is concerned, if bottles containing useful amounts of unused gas have to be returned to the supplier.

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The practice of using bottled gas also has associated with it a large number of other problems such as the possibility of gas leaking from bottles, possibility of industrial disputes which can result in severe delays in delivery and in supply shortages, liabilities, high purchase and storage costs, freight charges, and so on.

To illustrate some of the conditions which the consumer of bottled gas must put up with, listed below is a summary of the "conditions of sale" which apply to the sale and distribution of bottled gas.

(a) The cylinder remains the sole property of the supplier, which retains the right to exercise at any time its proprietary powers in its discretion.

(b) All cylinders and contents are forwarded at the expense and risk of the customers.

(c) It is the responsibility of the customers to provide adequate labour for the loading and unloading of all cylinders at the premises.

(d) Cylinders are to be returned to the supplier as soon as empty, carriage and freight charges paid.

(e) A cylinder is not 'returned' until received by the supplier at its works or warehouse or by its truck and a receipt of the suppliers form given for the same. No document purporting to be a receipt for any such cylinder shall be valid unless it is the suppliers printed form of receipt.

(f) Cylinders are not transferable and must not be used for any purpose other than as containers for the gas sold by the supplier and must not be delivered or sent for recharging to any place other than the suppliers gas station.

(g) The customer agrees not to resell to any person or Corporation, the gas contents of the cylinders of any part thereof.

(h) Customers are held responsible for all loss or damage to cylinders from whatever cause arising from the time of delivery until returned to the suppliers. (Customers are advised to cover the cylinders by insurance).

(i) Where a customer has not returned a cylinder in good order and condition within six months from the date of delivery, the supplier may, at it's option, charge the customer with an amount not exceeding the agreed value of the cylinder and the demurrage due in respect thereof, and such amount is payable by the customer as liquidated damages for the detention of the cylinder. Notwithstanding the payment of such amount in respect of any cylinder, it remains the property of the suppliers and the right of the suppliers to recover possession thereof is not affected in any way.

(j) No allowance is made on any residual gas returned in the cylinders.

(k) And many other conditions varying in the different countries in the world.

Another disadvantage, which is associated with oxy/hydrogen welding arises due to the marked ability of hydrogen to be absorbed by most metals. Thus when welding steel, for example, great care must be taken to ensure that excess hydrogen is not present otherwise it will be absorbed in the metal to cause loss of strength and brittleness. On the other hand, an excess of oxygen would cause burning of the metal and should thus equally be avoided. It is most important therefore that with oxy/hydrogen welding the mixture at the burner be adjusted to produce a neutral flame, that is, one in which there is neither excess hydrogen nor excess oxygen. In practice it is most difficult to maintain (and virtually impossible to judge by flame colour) a neutral

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flame, and for that reason oxy/hydrogen welding is not widely used despite the inherent advantages of low cost and high heat value offered by hydrogen as a fuel.

These and other disadvantages can be overcome to a significant extent by the present invention whereby hydrogen and oxygen fuel are generated simultaneously by electrolysis in an electrolytic cell and allowed to freely mix therein to form a stoichiometric mixture that will burn with a neutral flame. The fuel gas can be generated where and whenever required thereby eliminating the need for storage of bottles of gas and reliance on regular deliveries of gas which often cannot be guaranteed.

The method of the present invention requires no diaphragms or the like to separate the hydrogen and oxygen liberated by the electrolysis process and thereby enables considerable advantages to be realised over conventional electrolytic production of these gases. Such diaphragms have normally been regarded as essential for conventional electrolytic generators in order to separate the two gases that would otherwise form a highly explosive mixture; however, it has been found, in accordance with the present invention, that the two gases can be safely, and usefully, produced and utilised as a mixture for fuel purposes provided that suitable safety precautions, such as the employment of a flash-back arrestor, are taken. Such safety precautions may include, for example, the employment of a device which removes electrolyte vapour from the gas and at the same time acts as a flash-back arrestor. In obviating the need for diaphragms or the like the present invention enables the electrodes to be placed much closer together and avoids the high resistance associated with diaphragms, which in turn enables a significant increase in the rate of gas production for a given size of apparatus. In short the present invention enables the manufacture of small size equipment that is useful for a large variety of welding and similar work and that is not prohibitively bulky for the average situation: something which is impossible with conventional hydrogen/oxygen generating equipment.

In the development of apparatus from the basic concept of generation of hydrogen and oxygen electrolytically in a practical manner suitable for large industrial applications on the one hand, and small domestic applications on the other hand, a number of factors had to be taken into account, analysed and weighed one against the other. The following is a list of some of these factors to illustrate what has been involved.

(a) Endosmotic pressure to be balanced against the hydrostatic pressure of the fluid.

(b) Rate of flow of electric current in relation to the area of the electrodes.

(c) The prior art problem of removing the gases from anolyte and catholyte, before diffusion and before the electrolytes are intermixed.

(d) Effects of rapid changes in the rate of flow of electricity through the cell.

(e) Effects of auxiliary decomposition within the anode and cathode sides of the cell.

(f) The choice of the most readily ionised electrolyte of a maximum conductivity.

(g) The least possible spacing between anode and cathode that can be employed.

(h) A design of cell in which previously it was regarded impossible for the  $H_2$  and  $O_2$  given to become mixed with safety, which does away with diaphragms or the like which would increase the internal resistance,

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in which both hydrogen and oxygen can be mixed within the cell, and in which cells can be connected in series, parallel, or parallel and series to suit requirements.

(i) The choice of materials for the electrodes.

(j) The quantity of acids or alkali to be used.

(k) The shapes of cells according to purpose of the cells, and the application for which they are designed.

(l) The possibility of improvement with permanent or electro-magnetically induced fields applied to the electrolytic cells, to cause controlled separation of a quantity of the gases generated in the cells.

(m) Ensuring effective circulation of electrolyte between the electrodes, with as little electrical resistance as possible.

(n) The possibility of using sodium hydroxide or potassium hydroxide which, in concentrations from 10% up to 30%, which has negligible corrosion action on iron or nickel electrodes, apart from producing a solution of good conductivity.

(o) The use of the cooling effect by passing of hydrogen and oxygen gases, for cooling electrolyte in the cell, for controlling the cell temperature, preferably between  $40^\circ C$  to  $60^\circ C$ , at which temperature the bonds between hydrogen and oxygen need a minimum of electrical energy to break.

(p) The separation of hydrogen and oxygen from a mixture, using, possibly, a permanent magnetic field, or an electro-magnetic field which can be controlled to obtain a desired separation between the hydrogen and oxygen. Based on this principle, the oxygen could be substantially separated from the mixture and the hydrogen could be absorbed by, for example, selected metals, which have high absorption affinity for hydrogen (for example, palladium which absorbs 900 times more hydrogen from its volume). Also, using the principle of the invention, hydrogen and oxygen can be generated in large quantities with small units and the oxygen could, for example, be separated and used to supply hospitals, baby rooms, air conditioning systems, or for any other application, when oxygen is required. Oxygen can, in this way, be generated much faster and more conveniently than with conventional electrolytic generating equipment.

(q) The possibility of absorbing the hydrogen or oxygen by specially selected materials in small containers and where the absorbed gas can be extracted when desired for welding or brazing where it would be inconvenient or impossible to do so with conventional equipment.

(r) Making the welding operator entirely independent of any gas suppliers.

(s) The generation of cheap gas, up to six to seven times cheaper than normal gas supplies.

(t) The design of equipment which gives not only professional welders, but handymen, or people who would like to do welding at home with oxy-welding apparatus, but would do it only occasionally and could not justify the expense associated with conventional gas supplies. Such people cannot justify paying for bottles of gas for a single welding only (having to keep the bottles, paying rent for them to keep them up to two years, to perform the next welding). For this reason, the welding apparatus made possible by the present invention is ideal because it produces gases for welding at the time and in the quantity that is needed.

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(u) Hydrogen/oxygen welding has the advantage that it does not pollute the atmosphere as does oxy/acetylene welding.

(v) The design of electrolytic cells which are safe to use as well as convenient, which cells may incorporate their own flash-back arrestors as a safety precaution or an equivalent means, to prevent the hazards of explosion or fire.

(w) The control of the current which passes through the cells, the temperature of the cell, which is a function of current, the control of the separation of the gases, and the removal from the gases of electrolyte vapours. In this regard there has been designed a special unit with preferably conical electrodes, and a flash-back arrestor. The flash arrestor may be constituted by a pellet of porous material, or a long capillary pipe located between the gas generator and a burner head. The fire hazards associated with a mixture of hydrogen and oxygen cannot be over-emphasised and indeed it is probably mainly because of the recognised dangers associated therewith that extreme lengths have been taken to separate the two gases completely until they reach the burner. In accordance with the present invention it has been realised that, contrary to long standing opinions, the gases can be safely mixed together even when being produced and as a result many desirable advantages can be realised.

(x) The provision of one or more safety valves adjusted to convenient pressure for releasing excessive pressures in the cell (for example, greater than 30 p.s.i.) which may result, for example, if a current control mechanism fails. The safety valves could be attached to an alarm, for example, to indicate a failure in the current control mechanism or the cut-off switches, etc.

(y) Porous material may conveniently be placed in the burner head, so that backfire through the burner into the cell cannot occur.

In summary, the present invention contemplates, as an important feature thereof, a universal welding apparatus capable of being used to perform different types of welding operations based on the utilisation of hydrogen and oxygen, making full use of the advantages which can thereby be realised, and equipment which can be made small and portable compared with existing apparatus such as that presently used for gas welding using bulky bottled hydrogen. To generate the fuel, in accordance with the invention a small compact electrolytic cell is made possible in which the only raw material which has to be replenished from time to time is water and which can be used whenever a source of electrical energy is available to supply the necessary amount of hydrogen or hydrogen and oxygen mixture for performing atomic welding or hydrogen/oxygen flame welding. In its simplest form, the gas generating apparatus of the present invention comprises an electrolytic cell adapted to be connected to an energy source, optionally through a step down transformer and rectifier, and having means for connection to a burner, preferably through a flashback arrestor as a safety precaution.

The apparatus may be combined with a transformer as a single compact unit and for convenience the transformer may be provided with several windings to enable it to be used for auxiliary purposes such as battery charging, electroplating, arc welding or to provide an arc for atomic welding.

It has been found that a single electrolytic cell operating without diaphragms at several hundred amps will generate hydrogen and oxygen at a reasonable rate for

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small welding and brazing work but for larger work (for example, the welding of 10 mm steel plate) the required amperage becomes excessive (typically of the order of 900A or more) when considering the size of conductors and transformer and the problem of heat generation. Accordingly, in one aspect of the invention these problems can be significantly reduced by arranging a plurality of cells in series and using a much smaller current to obtain the same effective gas output. In effect the capacity of a series of cells for a given current input is that of a single cell multiplied by the number of cells. Alternatively the current requirement is reduced by a factor equal to the number of cells — for a given rate of gas production.

Even so a large number of separate cells can be excessively bulky for portable applications and in a further aspect of the invention, therefore, the bulk can be greatly reduced by arranging the cells as a single unit in which a number of electrodes, effectively in series, are arranged adjacent each other in a common electrolytic chamber, the chamber being provided with a gas collection space and an outlet for connection to, for example, gas burner means. Furthermore, only the end electrodes need be connected to an external source of electrical energy and the arrangement as a whole can be made extremely efficient and compact. Additionally the need for a transformer for most applications can be eliminated by such an arrangement so that the apparatus can be designed to be electrically connected directly to a main electrical supply, through a bridge rectifier if desired. By eliminating the need for a transformer, the gas generating equipment as a whole can be made surprisingly compact, to be well suited for small domestic requirements as well as heavy industrial requirements.

In another important aspect of the invention, there is provided a safety device which monitors the pressure of the hydrogen and oxygen being generated and regulates the current flowing through the cell(s) to increase or decrease the rate of gas production depending on the pressure. In one form the device comprises a chamber containing two electrodes, at least one of which is conical, arranged in the chamber (which normally contains a conductive liquid) and the electrodes being connectable in series with one or more electrolytic cells used for oxygen/hydrogen production.

The pressure responsive, current regulating device can be designed as an integral part of the electrolytic cell(s) or can be used as an attachment connectable externally and in series with the gas generating cell(s). The device can also be designed to combine the functions of a current regulating device and a flash-back arrestor, the latter function ensuring that a flame at the burner does not accidentally pass back through the hose lines to the highly explosive mixture in the gas generating cell(s). The device may incorporate a total current cut-out feature or may be used in combination with a cut-out device which fully interrupts the supply of electrical power should the pressure in the cell(s) accidentally exceed a maximum safe value. The current regulating device may also operate to regulate the current passing through the cells in accordance with the temperature to maintain the temperature within a desired range.

Referring to the drawings,

FIG. 1 is a schematic view of an embodiment of the invention,

FIG. 2 is a cross-sectional view of an electrolytic cell used in the invention,

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FIG. 3 is a view partly in section of a pressure responsive regulator for an electrolytic cell,

FIG. 4 is a cross-sectional view of a modified pressure regulator,

FIG. 5 is a schematic diagram of the torch operation, FIG. 6 shows a magnetic gas separation device, and FIG. 7 is a detailed schematic view of another embodiment of the invention.

Referring to the drawings, FIG. 1 shows schematically a single electrolytic cell 10 operating to produce a mixture of hydrogen and oxygen, which mixture is passed through a flash-back arrestor 11 to a burner 12. The cell 10 contains two plate electrodes 10a and 10b immersed in an electrolyte consisting of a solution of KOH in water and connectable through terminals 13 and 14 respectively to a source of a.c. or d.c. electricity. Preferably, d.c. is used as the electrical impedance of the cell, is much lower for d.c. than for a.c. The source of electricity may be a transformer, typically of 300 Amps output rating, connected to the cell through a bridge rectifier. The flash-back arrestor 11 is constituted by a water bath in which gas liberated in the cell 10 passes through a tube 15 into the water bath 11 and thence through a tube 16 to the burner 12. The arrangement is suitable for small welding and brazing work but becomes too bulky for very large work.

FIG. 2 illustrates in vertical cross-section an electrolytic cell 20 which requires a much lower current than the cell illustrated in FIG. 1 for a given current input. The cell 20 comprises what is in effect a series of cells constituted by a plurality of plate electrodes immersed in a solution of KOH in water. For convenience the electrodes are designated as 20a for the two electrodes at the ends and 20b for the intermediate electrodes. The electrodes 20a are connected, via conductors 21 to terminals 22 for connection to an external supply of electricity. The mixture of hydrogen and oxygen which is evolved at the electrodes when an electric current is applied, passes through an outlet opening 23 to a flash-back arrestor and thence to a burner (not shown in FIG. 2). The series of electrodes 20a and 20b are sealingly mounted in a tube 24 of insulating material which is provided with restricted apertures 24a at the top and 24b at the bottom, between each pair of electrodes. The apertures 24a permit gas to escape into the space above the surface of the electrolyte and the apertures 24b permit electrolyte to enter freely into the spaces between each pair of electrodes. By virtue of this arrangement the electrical resistance between any two adjacent electrodes is for less than that between non-adjacent electrodes so that the arrangement is effectively one of a large number of individual cells connected in series. A very compact arrangement is therefore obtained but one which permits a relatively high gas production rate for a reasonably low current input. For example, a structure like that shown, consisting of the equivalent of, for example, 120 cells can generate gas at a current input of 15A (at, for example, 240V) equal to that of a single cell requiring a current input of approximately 1800A. This means in practice that a relatively portable apparatus can be produced which can be connected directly, without a transformer, to most domestic electrical supplies and which can maintain a sufficient rate of gas production for most types of welding work.

An advantage which particularly distinguishes the arrangements disclosed from conventional gas welding apparatus is that the hydrogen and oxygen are automati-

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cally produced in substantially the correct proportions to give a neutral flame. No mixing valves are required and even unskilled personnel can produce satisfactory welds without difficulty. In fact indications are that many welds can be produced better than by any other welding process.

FIG. 3 illustrates a pressure responsive safety device 30 operably connected in series (electrically) with an electrolytic hydrogen/oxygen cell 31 for regulating the current passing therethrough in accordance with the gas pressure being generated. The device, or cell 30 comprises a chamber 30' in communication with a reservoir 32 via a passage 33. Two conical electrodes 34 and 35 are mounted in spaced relation within the chamber and connected in series between a d.c. source (not shown) and the electrolytic cell 31. An electrolytic solution of KOH and water is provided within the chamber, portion of which enters the reservoir 32. When the cell 31 is operating to produce hydrogen and oxygen the pressure of the gas being produced acts on the surface of the electrolyte in the chamber 30' to displace an amount of the electrolyte into the reservoir 32 against back pressure exerted by air trapped in the reservoir, the amount of electrolyte displaced depending on the pressure of the gas in the chamber 30'. At the same time the area of contact between the electrodes and the electrolyte in the cell 30 reduces in proportion to the drop in electrolyte level, causing the electrical resistance of the cell 30 to rise and the current passing therethrough to fall. Should the gas pressure drop the electrolyte level in the cell 30 will rise and the current passing into the cell 31 will also rise. Thus the cell 30 operates to regulate the rate of gas production in accordance with the pressure produced and prevents excess gas pressure to build up in the cell 31.

FIG. 4 illustrates an alternative form of safety device which is operable to make or break the connection between an electrolytic hydrogen/oxygen cell (not shown in FIG. 4) and an electric current source. The device comprises a cylindrical container 40 in fluid communication with a liquid reservoir 41 via a passageway 42, and a quantity of mercury (42') contained in the container and reservoir. Two electrodes 43 and 44 are disposed one above the other in the container 40 and are normally immersed in the mercury with a conductive path thereby formed between them. The container is connected electrically in series with an electrolytic cell (or cells) and in gaseous communication therewith through a hose 45. An increase in gas pressure resulting from generation of gases by the electrolytic cell(s) causes the mercury to be displaced towards the reservoir and the mercury level in the container 40 to fall. When the pressure exceeds a predetermined level the mercury level falls below that of the electrode 43 and electrical connection between the two electrodes is broken. The electrical connection is again restored when the gas pressure falls. A non-flammable liquid, such as silicone oil or freon is provided on top of the mercury to ensure that any arc which may be generated between the electrode 43 and the mercury is totally isolated from the gases above the liquids.

FIG. 5 shows schematically an arrangement whereby an exceedingly hot flame can be produced using the gaseous mixture generated electrolytically by the apparatus previously described. In this arrangement a mixture of hydrogen and oxygen, preferably in stoichiometrical proportion, is passed via a line 50 between a pair of tungsten electrodes 51 to produce molecular dissocia-

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tion of the hydrogen and the oxygen and a very hot flame 52. It can be appreciated that whereas in an atomic hydrogen flame a significant temperature rise is obtained by striking an arc in the hydrogen, an even greater temperature rise can be realised by striking the arc between the oxygen as well since the dissociation energy of molecular oxygen is of the same order of magnitude as that of molecular hydrogen.

FIG. 6 illustrates an arrangement for the magnetic separation of oxygen from a mixture of oxygen and hydrogen, whereby the oxygen can be used for flame cutting. The apparatus consists of a chamber 60 containing a magnet 61 and located in a conduit 62. A mixture of hydrogen and oxygen is passed through the conduit and around the magnet 61. The diamagnetic oxygen is diverted by the magnetic field into a transverse passageway 63 to a central conduit (not shown) leading from this passageway and thence to a flame-cutting head. The paramagnetic hydrogen continues along the conduit, past the magnet and can be allowed to escape or can be collected, as desired. If the magnet is an electromagnet it can be turned off when hydrogen and oxygen is required as a mixture, and in that case the downstream side of the conduit 62 can be closed off to prevent the loss of gas.

FIG. 7 illustrates a complete oxy-hydrogen generating/welding apparatus comprising a gas generator 70, a current regulating cell 71 and a power supply 72. The construction of the electrodes 73 of the generator 70 and 74 of the cell 71 are identical with those illustrated in FIGS. 2 and 3 respectively. In this arrangement, however, the gas generator 70 and cell 71 are combined as an integrated unit and as such has some features not found in the arrangements shown in FIGS. 2 and 3. In particular the chamber 75 of the generator 70 and the chamber 76 of the current regulator cell 71 are separated by two partitions 77 and 78 defining between them a passageway communicating between the two chambers. The respective electrodes of the cell 71 and generator 70 are connected electrically in series with the power supply.

Gas produced by electrolysis in the chamber 75 rises into the space in the chamber above the electrodes 73, passes down the passageway between the partitions 77 and 78, bubbles through the electrolyte in the chamber 76 and thence passes through an outlet opening 79 to a burner 80. An air trap reservoir 81 is formed integrally with the cell 71 and is in liquid communication therewith through an opening between the bottom of the reservoir and the cell. When the pressure of the gas generated by the generator 70 rises, this pressure causes the electrolyte in the chamber 76 to be displaced into the reservoir 81 resulting in a reduction of the current being passed to the generator 70 by the mechanism previously described in relation to FIG. 3 of the drawings. In this way the cell 71 effectively monitors the gas pressure and regulates the current to maintain an approximately constant pressure. To ensure against the possibility that the pressure should accidentally exceed a predetermined maximum safe value, a spring-loaded safety pressure valve 82 is provided at the top of the reservoir 81 to release the excess pressure into the atmosphere.

The burner 80 is provided with a flash-back arrestor in the form of a porous ceramic pellet 83 located in the gas flow path between the handle part 84 of the burner and the burner tip 85. The flash-back arrestor acts by quenching any flame blowing back into the burner be-

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fore the flame has a chance to reach the hose 86 connecting the burner with the gas generator.

The power supply is of the universal type, that is, it is provided with a transformer 87 connectable to an alternating current electrical supply and provided with a number of electrical outlets for various purposes. One winding of the transformer is connected to a bridge rectifier which provides the d.c. current for the gas generator. Another winding is used for arc welding or can be used to supply an arc for atomic oxy-hydrogen welding. It will be appreciated that the transformer is optional and that the generator can be connected directly to the mains. In fact the bridge rectifier is not essential either and can be omitted if desired.

In the operation of apparatus of the type described it is often required to conveniently change between neutral and oxidising flames, for example when changing from a welding operation to a cutting operation and the present invention makes provision for the variation of these functions. Briefly, in accordance with the present invention, apparatus for either oxy-hydrogen welding or cutting may comprise a first electrolytic generator for generating hydrogen and oxygen by the electrolysis of water in substantially stoichiometric proportions to produce a neutral flame and a further electrolytic generator from which hydrogen and oxygen are separately delivered, with means for adding either the hydrogen from this further cell, or the oxygen from the further generator to the gas mixture obtained from the first generator. This arrangement results in a most efficient combination of functions when a neutral flame or other is required. The hydrogen gas produced by the further generator, when added to the flame mixture, burns with atmospheric oxygen thereby producing a reducing flame. When an oxidising flame is required, the additional hydrogen is cut off and the oxygen produced by the further generator is added to the flame mixture. It will be appreciated that various designs can be employed for either generator, for example, they may be completely independent or they may share a common electrolyte. The further gas generator can also, in practice, be made somewhat smaller than the other generator since it does not have to produce the bulk of the gas required.

It has been found that welding with hydrogen and oxygen in an exact 2 to 1 ratio (as when the gases are produced electrolytically) results in a particularly clean, oxide free welded surface and a strong welded joint. For the same quality welding to be produced by conventional gas welding technique substantially greater skill is required and, in the case of conventional hydrogen welding, for example, good welded joints are obtained only with great difficulty due to the extreme difficulty in obtaining and maintaining a neutral flame. With the method of the present invention there is no difficulty in obtaining a neutral flame, and hence the ease with which high quality welds can be obtained.

Finally, it can sometimes be convenient to store hydrogen and/or oxygen, generated electrolytically in a specially designed container, or to slowly accumulate these gases and then, when required, using the accumulated stored gas for extra heavy work for a short time. It is quite hazardous to pressurise a mixture of hydrogen and oxygen under very high pressures, of course, but it is possible, in accordance with one aspect of the invention, to store a useful amount of gas in a relatively small volume at low pressures and this can be done by using a highly gas absorbent metal in the storage container.

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The metal palladium, for example, can absorb up to 900 times its own volume of hydrogen and can be used with advantage for this application. In fact useful amounts of hydrogen, for small scale brazing work can readily be stored in a small hand held container, containing a gas absorbent material.

I claim:

1. A method of oxy/hydrogen welding, brazing or the like, characterized by electrolytically generating a mixture of hydrogen and oxygen in substantially stoichiometric proportions by passing an electric current between electrodes immersed in an aqueous electrolyte contained in at least one electrolytic chamber, passing the mixture of hydrogen and oxygen from said at least one chamber through an aqueous electrolyte contained in a pressure sensitive regulating device having at least one pair of electrodes connected electrically in series with said electrodes in said at least one electrolytic chamber, which electrolyte in said regulating device is displaceable as a result of pressure of said mixture of hydrogen and oxygen to proportionately increase the electrolyte resistance between said pair of electrodes and consequently reduce the electric current passing between said pair of electrodes in said regulating device and said electrodes in said at least one electrolytic chamber in accordance with an increase in pressure therein, passing said gaseous mixture through flashback arresting means and thence through a burner nozzle, producing an arc between electrodes arranged downstream of said burner nozzle and in the path of said gases so as to produce dissociation of said gases into atomic hydrogen and atomic oxygen, and burning said hydrogen and oxygen to produce a flame, the temperature of the flame exceeding the normal temperature of combustion of molecular hydrogen and oxygen.

2. Method as claimed in claim 1 wherein excess oxygen is added to the mixture of hydrogen and oxygen and the flame is used for metal cutting.

3. Method as claimed in claim 1 wherein said electric current is passed through a plurality of electrolytic cells connected electrically in series, the hydrogen and oxygen liberated in each cell being collected as a stoichiometric mixture which is passed through said pressure sensitive regulating device.

4. Method as claimed in claim 3, wherein the plurality of electrolytic cells is constituted by a plurality of electrodes arranged side-by-side in an electrolytic bath in a manner to be electrically in series, with the electrodes at each end of the series being connectable with an external source of electrical energy.

5. The method of claim 3, further characterized by using an A.C. supply in combination with a transformer to provide the electrical current for the cells.

6. Method as claimed in claim 3, wherein additional hydrogen and oxygen are generated separately in a further electrolytic cell or cells and the additional hydrogen and/or oxygen so generated is/are added to the said mixture of hydrogen and oxygen before the mixture is passed through said arc.

7. Metal cutting according to claim 6, wherein the additional oxygen is obtained by magnetic separation thereof from a mixture of hydrogen and oxygen.

8. The method as claimed in claim 1, wherein the arc welding is accomplished by the use of an electrical transformer.

9. Apparatus for the generation of hydrogen and oxygen and utilization of same for welding, brazing or the like, said apparatus comprising at least one electro-

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lytic chamber having electrodes immersed in an aqueous electrolyte contained in said chamber, a pressure sensitive regulating device containing an aqueous electrolyte, at least one pair of electrodes immersed in the aqueous electrolyte contained in said regulating device and connected in series with said electrodes contained in said at least one electrolytic chamber, a passageway connecting said pressure sensitive regulating device with said at least one electrolytic chamber, said aqueous electrolyte in said pressure sensitive regulating device being displaceable relative to said pair of electrodes immersed therein so as to proportionately increase the electrolyte resistance between said pair of electrodes and consequently reduce the electric current passing in series between said pair of electrodes and said electrodes in said at least one electrolytic chamber in accordance with an increase in pressure of said gases, an outlet to said regulating device, means passing said gaseous mixture from said outlet through a flashback arresting means to a burner nozzle, and a pair of electrodes arranged downstream of said burner nozzle in the path of said gases therefrom, said electrodes being connectable to a source of electrical arc energy for causing dissociation of said gaseous mixture into atomic hydrogen and atomic oxygen.

10. Apparatus as claimed in claim 9, wherein said at least one electrolytic chamber comprises a plurality of electrolytic cells connected electrically in series or series parallel and arranged each to generate a mixture of hydrogen and oxygen by electrolytic dissociation of said aqueous electrolyte.

11. Apparatus as claimed in claim 10, wherein the plurality of electrolytic cells is constituted by a plurality of electrodes arranged in close-spaced relation in a manner to be effectively in series or series parallel the electrodes at each end of the series being connectable through terminals to a source of electrical energy.

12. Apparatus as claimed in claim 11, wherein the electrodes comprise a series of parallel plates mounted in spaced relationship along an insulated tube and in sealing relationship therewith, with apertures being formed in the tube between each pair of adjacent plates to provide for passage of electrolyte into the space between each pair of plates, and the escape of gas therefrom.

13. Apparatus as claimed in claim 9, including means for the separation of oxygen from a mixture of hydrogen and oxygen and passing the oxygen so separated as excess oxygen to the burner head.

14. Apparatus as claimed in claim 13, wherein said means comprises a passageway for the passage of a mixture of hydrogen and oxygen, means for producing a magnetic field in the passageway, to separate the hydrogen and the oxygen, and means for collecting either of the hydrogen or oxygen so separated.

15. Apparatus as claimed in claim 9, wherein a safety pressure release valve means is provided in combination with pressure sensitive regulating device to release gas pressure therefrom when exceeding a predetermined value.

16. Apparatus as claimed in claim 9, including transformer means in combination therewith for arc welding, battery charging, supply of current of the electrolytic cells or the like.

17. Apparatus as claimed in claim 9, including a bridge rectifier in circuit with the electrolytic cell(s).

\* \* \* \* \*

**United States Patent** [19]

[11]

**4,111,161****Ueno et al.**

[45]

**Sep. 5, 1978****[54] ENGINE OPERATED ON  
HYDROGEN-SUPPLEMENTED FUEL**

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**[21] Appl. No.:** 624,921

**[22] Filed:** Oct. 22, 1975

**[51] Int. Cl.<sup>2</sup>** ..... F02B 43/08

**[52] U.S. Cl.** ..... 123/3; 123/DIG. 12;  
123/120

**[58] Field of Search** ..... 123/DIG. 12, 3, 1 A,  
123/120, 141, 30 C, 188 S, 188 M, 119 E

**[56] References Cited****U.S. PATENT DOCUMENTS**

1,856,328 5/1932 French ..... 123/30 C  
2,183,674 12/1939 Erren ..... 123/DIG. 12

2,593,769 4/1952 Kollsman ..... 123/188 S  
2,937,634 5/1960 Kelsaux ..... 123/DIG. 12  
3,407,790 10/1968 Antonsen ..... 123/120  
3,678,905 7/1972 Diehl ..... 123/188 M  
3,908,606 9/1975 Toyoda ..... 123/DIG. 12  
3,911,873 10/1975 Dave ..... 123/188 M  
3,923,027 12/1975 Daniels ..... 123/141  
3,946,711 3/1976 Wigal ..... 123/119 E  
3,954,092 5/1976 Polaner ..... 123/120  
3,970,054 7/1976 Henault ..... 123/DIG. 12

**FOREIGN PATENT DOCUMENTS**

531,430 1/1941 United Kingdom ..... 123/3

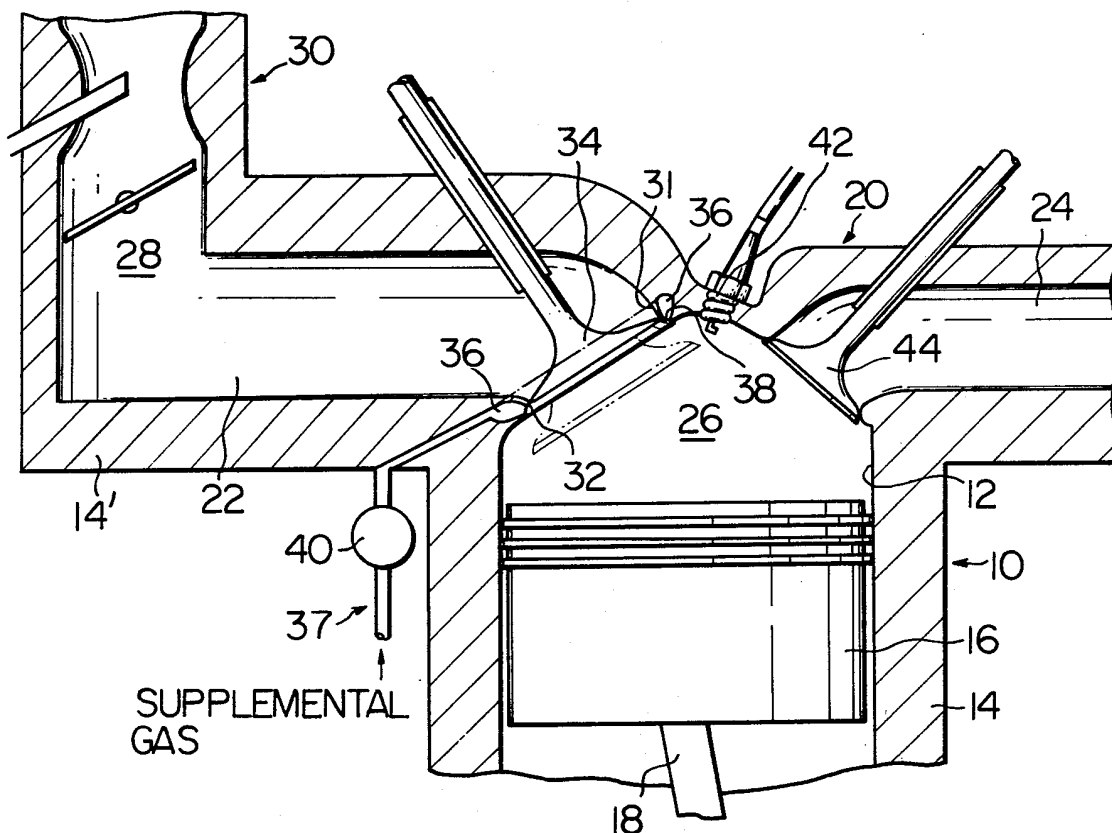
*Primary Examiner*—Ronald H. Lazarus

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J. Lobato; Bruce L. Adams

**[57]****ABSTRACT**

A lean air-fuel mixture and hydrogen gas are introduced into the combustion chamber so that high concentrations of hydrogen form about the spark plug and combustion chamber walls.

**4 Claims, 5 Drawing Figures**



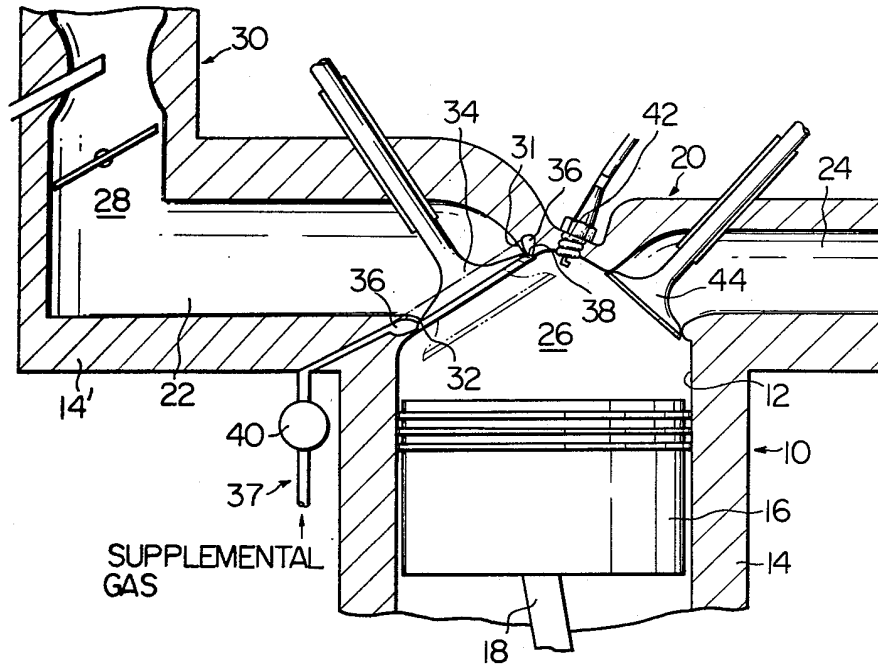
**U.S. Patent**

**Sept. 5, 1978**

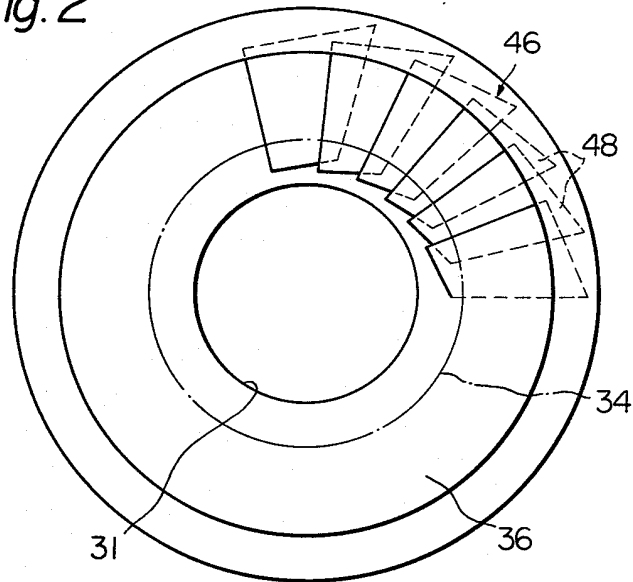
**Sheet 1 of 2**

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*Fig. 1*



*Fig. 2*



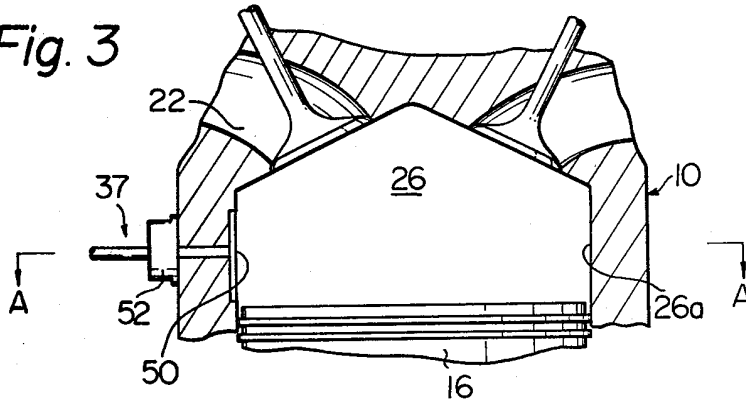


**U.S. Patent**

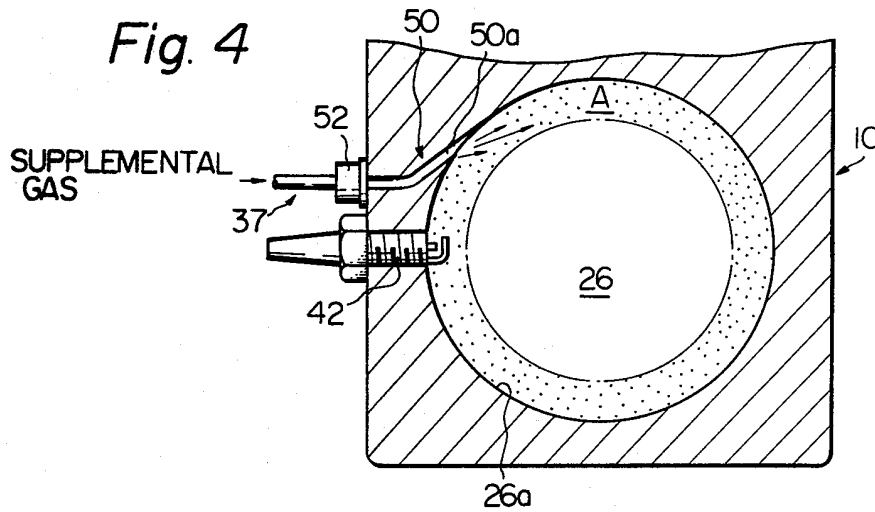
**Sept. 5, 1978 Sheet 2 of 2**

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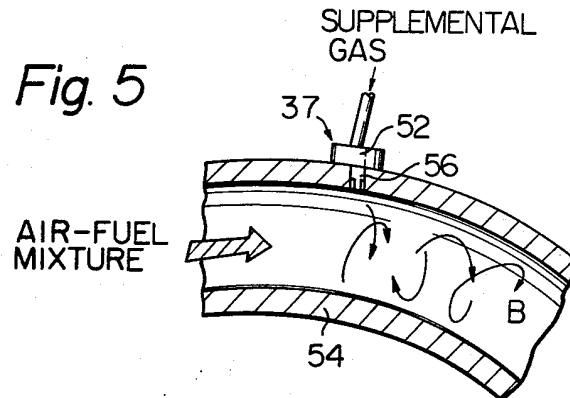
*Fig. 3*



*Fig. 4*



*Fig. 5*



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## ENGINE OPERATED ON HYDROGEN-SUPPLEMENTED FUEL

### BACKGROUND OF THE INVENTION

This invention relates to a spark ignition internal combustion engine operated on a lean air-fuel mixture supplemented with hydrogen gas, and to a method of operating the same.

As is well known in the art, internal combustion engines that are operated on over lean air-fuel mixtures emit low levels of nitrogen oxide ( $\text{NO}_x$ ), carbon monoxide (CO) and hydrocarbons (HC). However, internal combustion engines operated on the over lean mixtures (for example, air-to-fuel ratio; 18 or more: 1) usually misfire and therefore stable operation is not possible. The misfiring results from failure to ignite the lean mixture which has low fuel particle density and consequential poor flame front movement in the combustion chamber after ignition.

To overcome the above mentioned drawback, operation of the engine on over lean mixtures supplemented with hydrogen gas has been proposed. In this operation, flammable hydrogen gas can be diffused among fuel particles in the combustion chambers and therefore misfiring is prevented and the flame front movement improved.

The prior art engine operation on the hydrogen-supplemented fuel has contributed to lowering the emission levels of  $\text{NO}_x$  and CO, however, a problem has been encountered in that the air-fuel mixture adjacent the inner wall of the combustion chambers is not effectively burned and therefore relatively high levels of unburned hydrocarbons are emitted. This results from the fact that the temperature of the inner wall surface of the combustion chambers is not increased due to the low calorific value of the lean mixture, and release or absorption of heat generated by combustion through the walls of the combustion chambers.

### SUMMARY OF THE INVENTION

It is, therefore, a principal object of the present invention to provide an improved spark-ignition internal combustion engine and an improved method of operating the engine to enable stable operation of the engine on over lean air-fuel mixtures with very low noxious gases emissions.

It is another object of the present invention to provide an improved spark-ignition internal combustion engine operated on over lean air-fuel mixtures supplemented with hydrogen gas and an improved method of operating the engine whereby the gas is supplied into the vicinity of the spark plug and the inner wall surface of the combustion chamber, thereby promoting smooth clean combustion of the entire air-fuel mixture.

### BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and features of the improved internal combustion engine and the method of operating same in accordance with the principle of the invention will become more apparent from the following description taken in conjunction with the accompanying drawings in which like reference numerals and characters designate corresponding parts and elements and in which:

FIG. 1 is a vertical transverse section view showing an internal combustion engine having a first preferred embodiment according to the principle of the invention,

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this view showing an annular gas passage for providing supplemental gas into a combustion chamber;

FIG. 2 is a plan view of an annular louver assembly which may be disposed within the annular gas passage in FIG. 1;

FIG. 3 is a vertical transverse section view showing an internal combustion engine having a second preferred embodiment according to the principle of the invention;

FIG. 4 is a plan view taken along a section line A—A in FIG. 3; and

FIG. 5 is a sectional view showing a runner of an intake manifold of an internal combustion engine having a third preferred embodiment in accordance with the invention.

### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown a first preferred embodiment according to the principle of the present invention, in which a spark-ignition internal combustion engine of the four-cycle valve-in-head type is designated by the reference numeral 10. The engine 10 is a multi-cylinder internal combustion engine, only one cylinder 12 of which is shown in the vertical transverse section in FIG. 1. The cylinder 12 is formed in the body casting portion 14 of the engine block (not shown). Reciprocally disposed in the cylinder 12 is a piston 16 which is operatively connected by a connecting rod 18 to a crank arm of a crankshaft (they are not shown).

Covering the upper portion of the cylinder 12 is a cylinder head structure 20 which is formed with an intake passage 22 and an exhaust discharge passage 24. The cylinder head structure 20 defines therein a hemispherical combustion chamber 26. The intake passage 22 is connected at one end thereof to the induction passage 28 of a carburetor 30 and at the other end thereof to the combustion chamber 26 through an intake port 31 which is defined by an annular intake valve seat 32. The carburetor 30 is set to produce an extremely lean air-fuel mixture having an air-fuel ratio of about 18 or more:1. The fuel used in this instance is hydrocarbon fuel such as gasoline or light oil. An intake valve 34 seated on the valve seat 32 is arranged to move to the position shown in broken lines to open the intake port. Shown adjacent the intake valve seat 32 and in the body casting portion 14' of the cylinder head structure 20 is an annular gas passage 36 which constitutes part of supplemental gas supply means 37 and is formed annularly along the valve seat 32 and communicates with the intake port 31 through an annular aperture 38 formed through the surface of the valve seat 32. The annular gas passage 36 is connected to a check valve 40 which in turn is connected to a supplemental gas source which supplies hydrogen gas, or a mixed gas of hydrogen gas and other gases such as carbon monoxide gas (CO) or carbon dioxide gas ( $\text{CO}_2$ ). A spark plug 42 or igniting means is disposed through the body casting portion 14' and its electrode (no numeral) projects into the combustion chamber 26 adjacent to the intake port.

An exhaust valve 44 is seated on the exhaust valve seat (no numeral) located at one end of the exhaust discharge passage 24 and is arranged to open to allow the burned gas produced in the combustion chamber 26 to exhaust from the engine 10.

With the arrangement mentioned above, when the intake valve 34 is open and the lean air-fuel mixture is

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introduced during the suction stroke of the engine 10, the supplemental gas in the annular gas passage 36 is injected from the annular aperture 38 into the air-fuel mixture passing through the intake port 31. Then, the supplemental gas flows into the combustion chamber 26 along the inner wall of the combustion chamber 26 enveloping therein the lean air-fuel mixture. Therefore, the hydrogen gas concentration is higher adjacent the inner wall surface of the combustion chamber and in the vicinity of the spark plug 42 compared with the central portion of the combustion chamber 26. Accordingly, the air-fuel mixture adjacent the inner wall surface of the combustion chamber is effectively burned as a result of the high concentration of flammable hydrogen gas mixed therewith. This occurs even in a quench area where a flame will normally extinguish and therefore generation of unburned hydrocarbons due to a cooled inner wall is prevented. In addition, the high concentration hydrogen gas adjacent the spark plug 42 provides reliable ignition of the lean air-fuel mixture around the spark plug 42 via the so-called stratified charge of the hydrogen gas and air-fuel mixture. Flame front movement in the combustion chamber 26 is readily carried out since the flammable hydrogen gas is dispersed through the combustion chamber 26.

It will be noted that an annular louver assembly 46 as shown in FIG. 2 may be disposed within the annular gas passage 36 for the purpose of providing the swirling movement to the supplemental gas to be introduced into the combustion chamber 26. The swirled supplemental gas effects better mixing between the hydrogen gas and the lean air-fuel mixture while providing a high concentration of hydrogen adjacent the inner wall surface of the combustion chamber 26. As seen, the louver assembly 46 has a plurality of inclined vanes 48 which are annularly aligned along the annular gas passage 36.

FIGS. 3 and 4 illustrated a second preferred embodiment according to the principle of the present invention in which a similar engine construction to that in FIG. 1 is shown except for the location of the supplemental gas supply means 37 and the spark plug 42. As shown, a gas injection nozzle 50 forming part of the supplemental gas supply means 37 is formed within the body casting portion of the engine 10. The gas injection nozzle 50 has a straight portion 50a which is open at one end thereof through the cylindrical wall 26a of the combustion chamber 26 and connected at the other end thereof to a supplemental gas injection device 52. The device 52 is in turn connected to the supplemental gas source and injects the supplemental gas at a pressure higher than that in the combustion chamber 26. It should be noted that the axis of the straight portion 50a of the injection nozzle 50 is approximately tangential with respect to the circumference of the inner cylindrical wall 26. The spark plug 42 is disposed through the cylindrical wall 26a and its electrode projects into the combustion chamber 26 adjacent the inner wall of the combustion chamber 26. With this arrangement, since the supplemental gas is injected tangentially into the combustion chamber 26 along the inner peripheral surface of the cylindrical wall 26a, the hydrogen gas concentration adjacent the cylindrical wall surface 26a is higher than at the central portion of the combustion chamber 26. Therefore, the layer A having a relatively high hydrogen gas concentration is formed adjacent the inner cylindrical wall surface 26a and the spark plug 42 to effectively burn hydrocarbons in the combustion chamber 26

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in the similar manner as described with reference to FIG. 1.

FIG. 5 illustrates a third preferred embodiment in accordance with the principle of the present invention in which a gas injection nozzle 56 forming part of supplemental gas supply means 37 is disposed through the wall of a runner 54 of an intake manifold (not shown). The gas injection nozzle 56 communicates via the supplemental gas injection device 52 with the supplemental gas source. It should be noted that the axis of the injection nozzle 56 is so oriented that the injected supplemental gas is swirled along the inner circumference of the runner 54 as indicated by arrows B. The axis of the injection nozzle 56 may be approximately tangential with respect to the inner circumference of the runner 54. In this instance, the lean air-fuel mixture from the carburetor flows inside of the rotationally flowing supplemental gas and therefore the layer of relatively high hydrogen gas concentration will be formed at the portion adjacent to the inner wall of the combustion chamber and at the portion in the vicinity of the spark plug (they are not shown in FIG. 5).

As is apparent from the foregoing description, the engine constructed and the method of operating same in accordance with the present invention make possible considerably lower emission levels of NO<sub>x</sub> and CO. They also make possible prevention of unburned HC generated in the quench areas since a relatively high concentration of flammable hydrogen gas is ignited by the spark plug and burns adjacent the inner wall surface of the combustion chamber to reliably ignite the over lean air-fuel mixture adjacent the hydrogen rich layer. In addition, according to the present invention, combustion in the combustion chambers is smooth and therefore stable engine operation is possible even if the engine is operated on an ultra-lean air-fuel mixture since the flame front movement in the combustion chamber is rapid and smooth due to the fact that combustion speed of air-fuel mixture containing hydrogen gas is considerably higher than that containing no hydrogen gas, and so-called stratified combustion is achieved in the combustion chamber.

What is claimed is:

1. An internal combustion engine having a combustion chamber defined between a surface of a cylinder head and a piston, comprising:

lean air-fuel mixture supply means for supplying air-fuel mixture leaner than stoichiometric into the combustion chamber through an intake port formed in the cylinder head;

means for defining an annular hydrogen gas supply passage in the cylinder head, said hydrogen gas supply passage being formed annularly around an intake valve seat secured to the cylinder head and communicable with the intake port through the surface of the intake valve seat;

a hydrogen gas source operatively connected to said annular hydrogen gas supply passage; and

a spark plug disposed through the cylinder head and in the combustion chamber, said spark plug being located adjacent the wall surface of the cylinder head defining the combustion chamber.

2. An internal combustion engine as claimed in claim 1, further comprising an annular louver assembly disposed in said annular hydrogen gas supply passage to generate a swirl of hydrogen gas as it enters the combustion chamber, and said louver assembly having a

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plurality of inclined vanes annularly aligned along the annular hydrogen gas supply passage.

3. An internal combustion engine having a combustion chamber defined between a surface of a cylinder head and a piston, comprising:

a carburetor operatively connected through an intake port to the combustion chamber, said carburetor providing an air-fuel mixture leaner than stoichiometric;

means defining an annular hydrogen gas supply passage in the cylinder head, said hydrogen gas supply passage being formed annularly around an intake valve seat secured to the cylinder head and communicatable with the intake port through the surface of the intake valve seat;

a hydrogen gas source operatively connected to said annular hydrogen gas supply passage; and

a spark plug disposed through the cylinder head and in the combustion chamber, said spark plug being located adjacent the wall surface of the cylinder head defining the combustion chamber.

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4. A method of operating an internal combustion engine having a combustion chamber defined between a surface of cylinder head and a piston, comprising:

supplying air-fuel mixture leaner than stoichiometric into the combustion chamber through an intake port formed in the cylinder head;

supplying hydrogen gas into an annular hydrogen gas supply passage formed in the cylinder head, said hydrogen gas supply passage being located around an intake valve seat and being communicatable with the intake port through the surface of the intake valve seat;

injecting hydrogen gas from said annular hydrogen supply passage into the intake port so as to form, adjacent the wall surface of the cylinder head, an air-fuel mixture layer having a hydrogen gas concentration higher than that of the central portion of the combustion chamber; and

igniting said air-fuel mixture layer formed adjacent the wall surface of the cylinder head by a spark generated from a spark plug disposed adjacent the wall surface of the cylinder head.

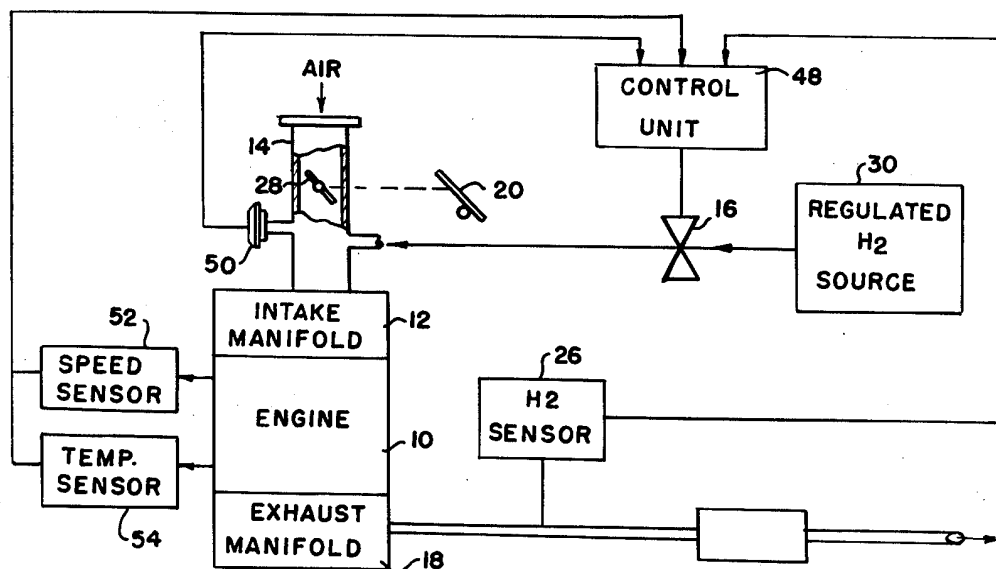
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**United States Patent** [19]**Wolber**[11] **4,141,326**[45] **Feb. 27, 1979****[54] CLOSED LOOP CONTROL SYSTEM FOR HYDROGEN FUELLED ENGINE****[75] Inventor:** William G. Wolber, Southfield, Mich.**[73] Assignee:** The Bendix Corporation, Southfield, Mich.**[21] Appl. No.:** 776,793**[22] Filed:** Mar. 11, 1977**[51] Int. Cl.<sup>2</sup>** ..... F02B 3/00**[52] U.S. Cl.** ..... 123/119 EC; 123/DIG. 12; 123/119 E; 123/120; 123/32 EE**[58] Field of Search** ..... 123/DIG. 12, 3, 119 E, 123/120, 119 EC, 32 EE**[56] References Cited****U.S. PATENT DOCUMENTS**

4,043,300 8/1977 Lombard ..... 123/32 EE

*Primary Examiner*—Wendell E. Burns*Attorney, Agent, or Firm*—James R. Ignatowski; Russel C. Wells**[57] ABSTRACT**

Disclosed herein is a closed loop fuel control system for a hydrogen fuelled engine embodying a hydrogen sensor in the exhaust manifold to provide a feedback signal indicative of the quantity of unburned hydrogen in the engine's exhaust. The system electronically controls or trims the fuel delivery to the engine in response to signals indicative of the engine's operating parameters and the signal generated by the hydrogen sensor to maintain the concentration of hydrogen in the exhaust at a predetermined level.

**33 Claims, 11 Drawing Figures**

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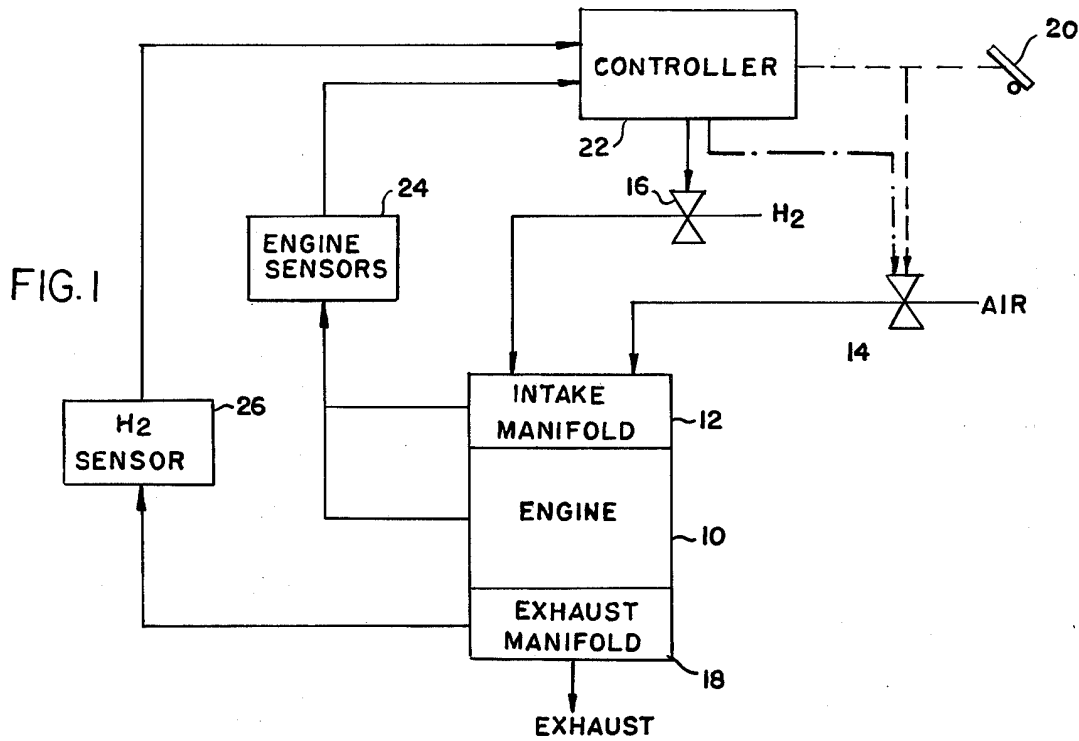
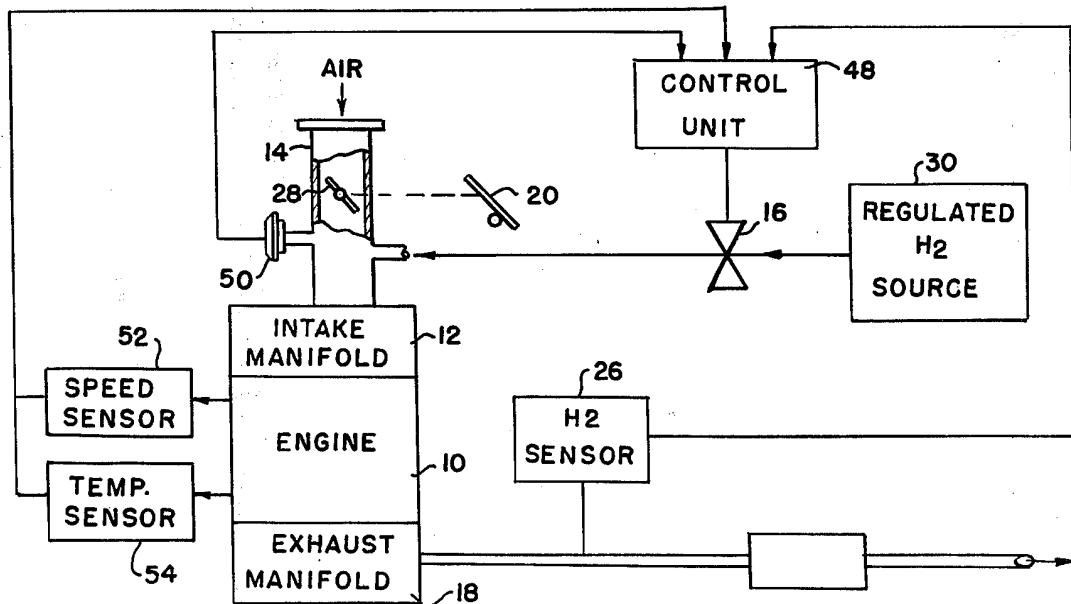


FIG. 6



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FIG. 2

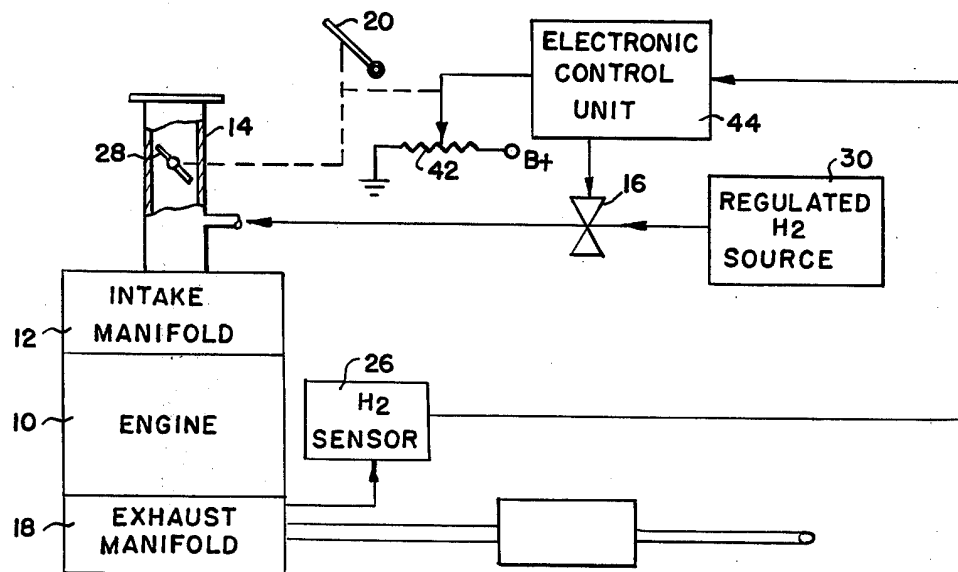
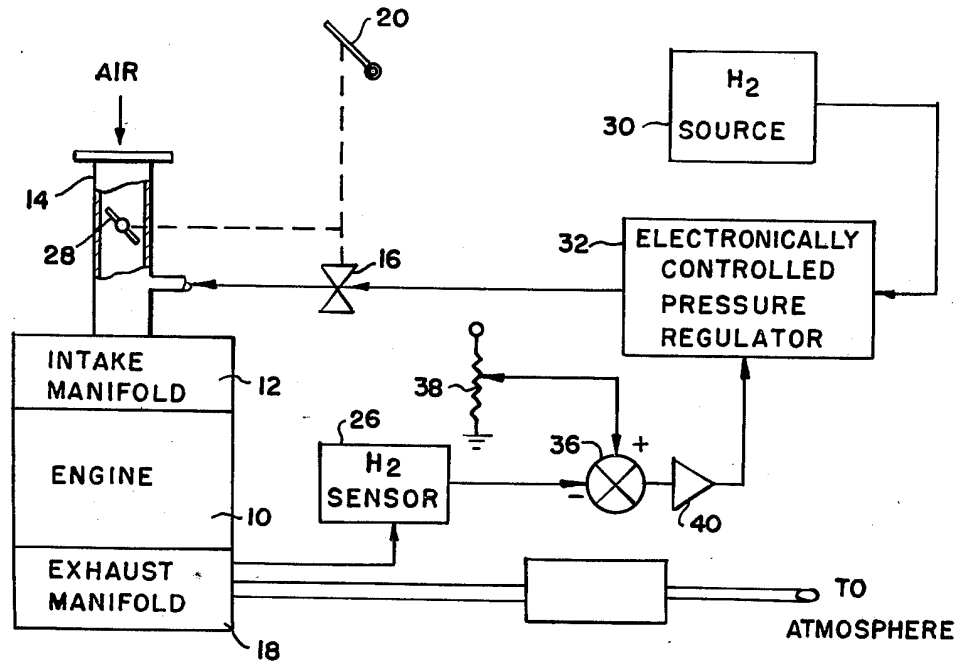


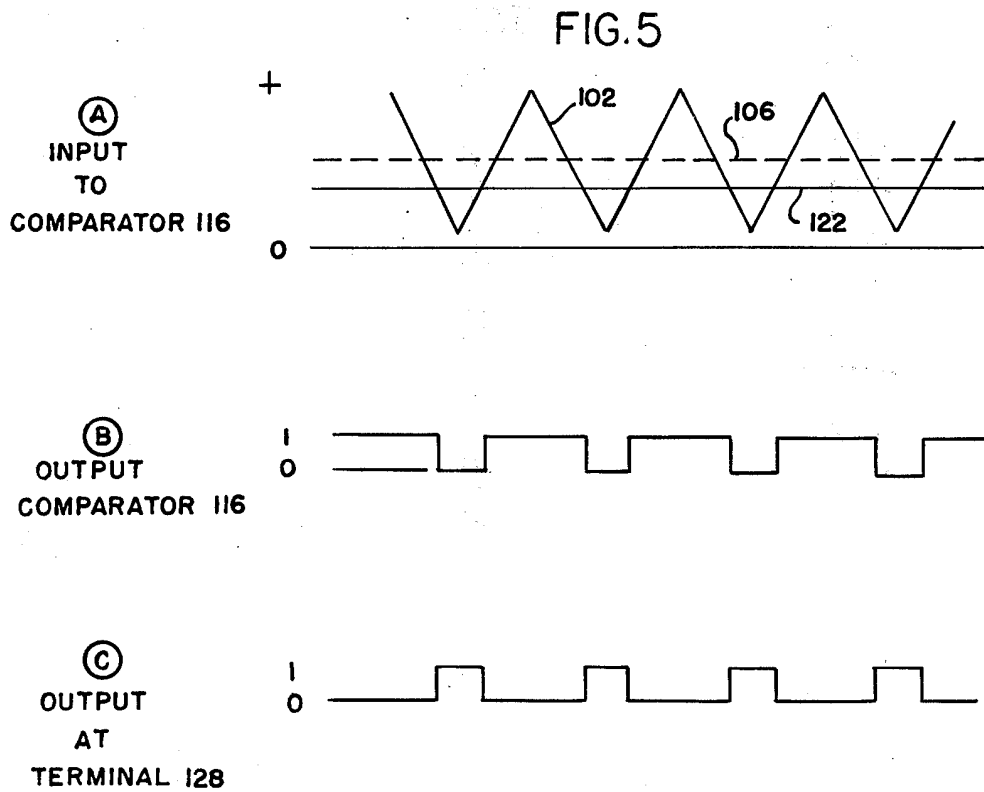
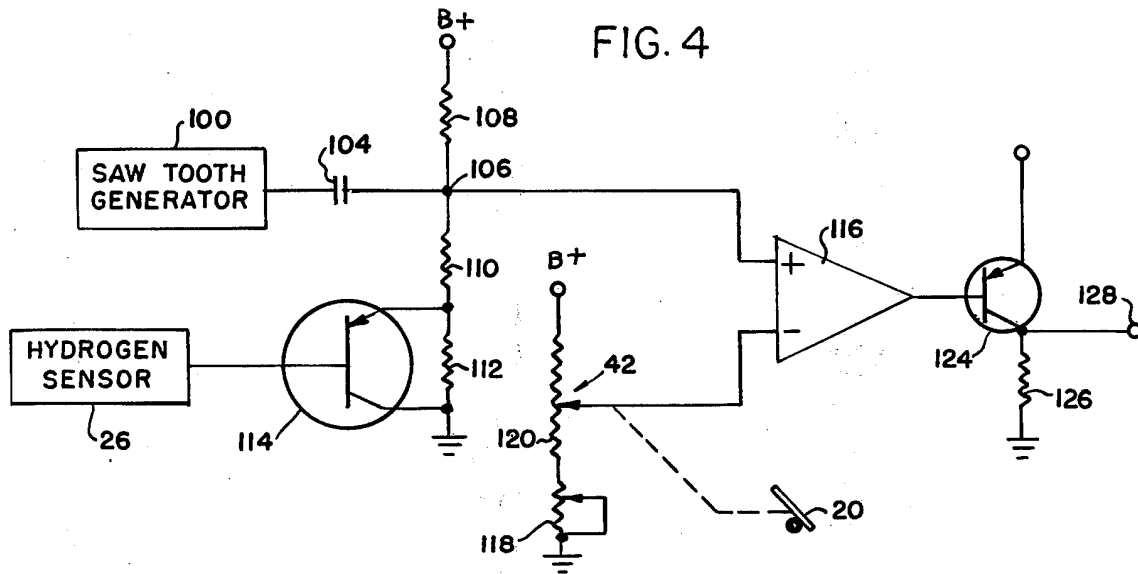
FIG. 3

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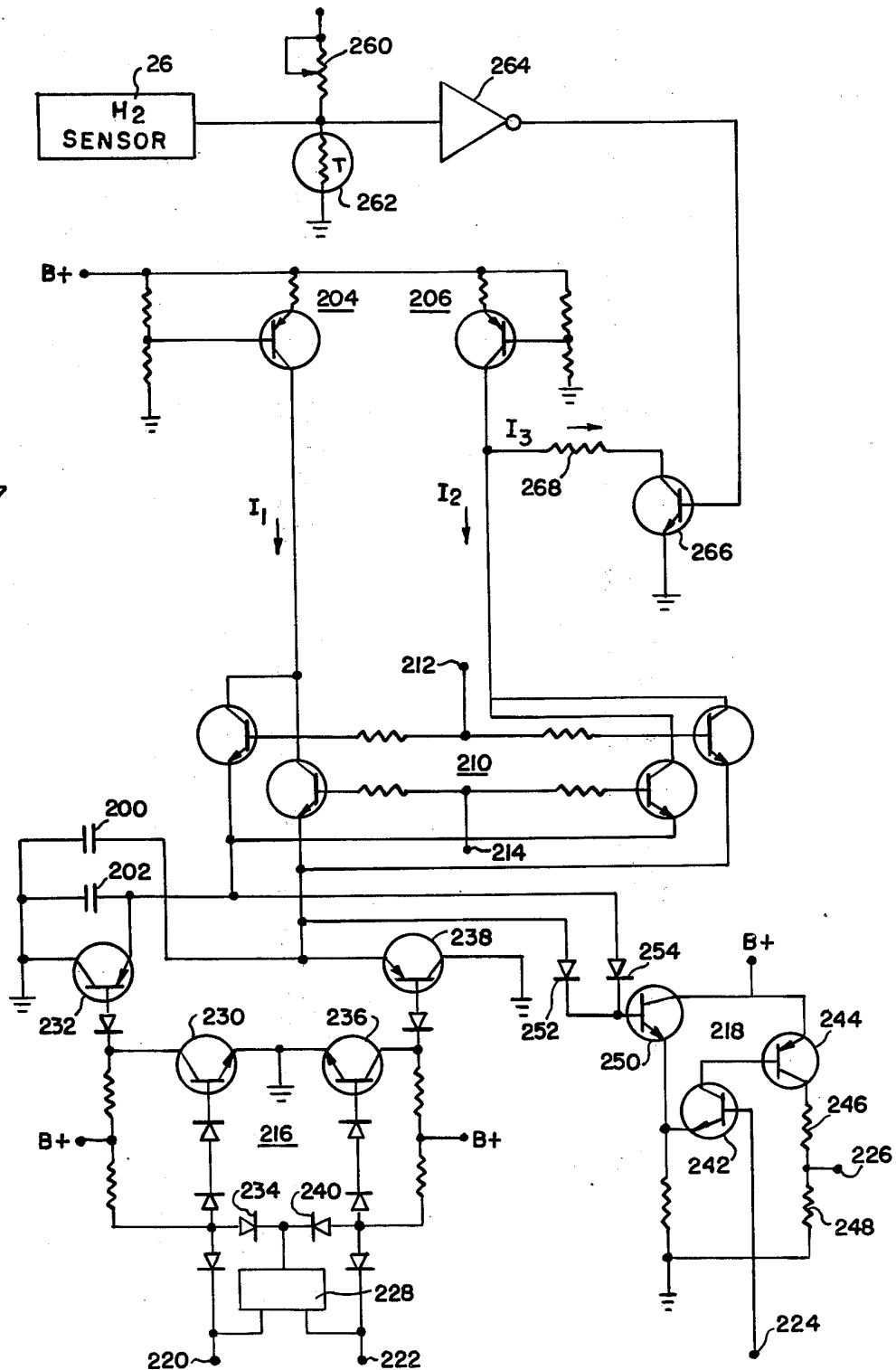


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FIG. 7



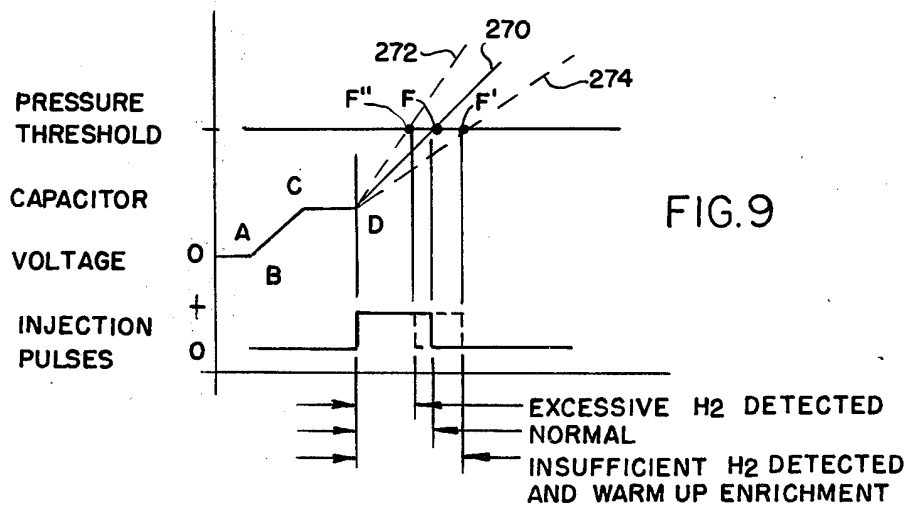
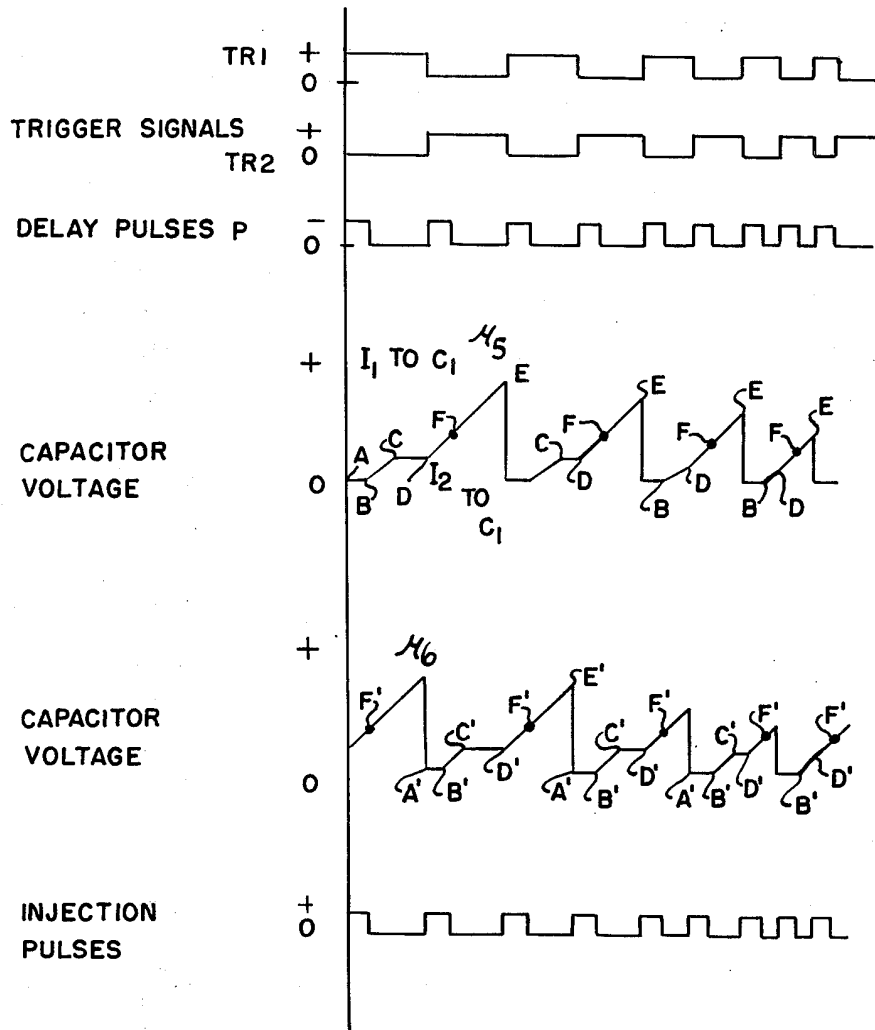
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FIG. 8



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FIG. 10

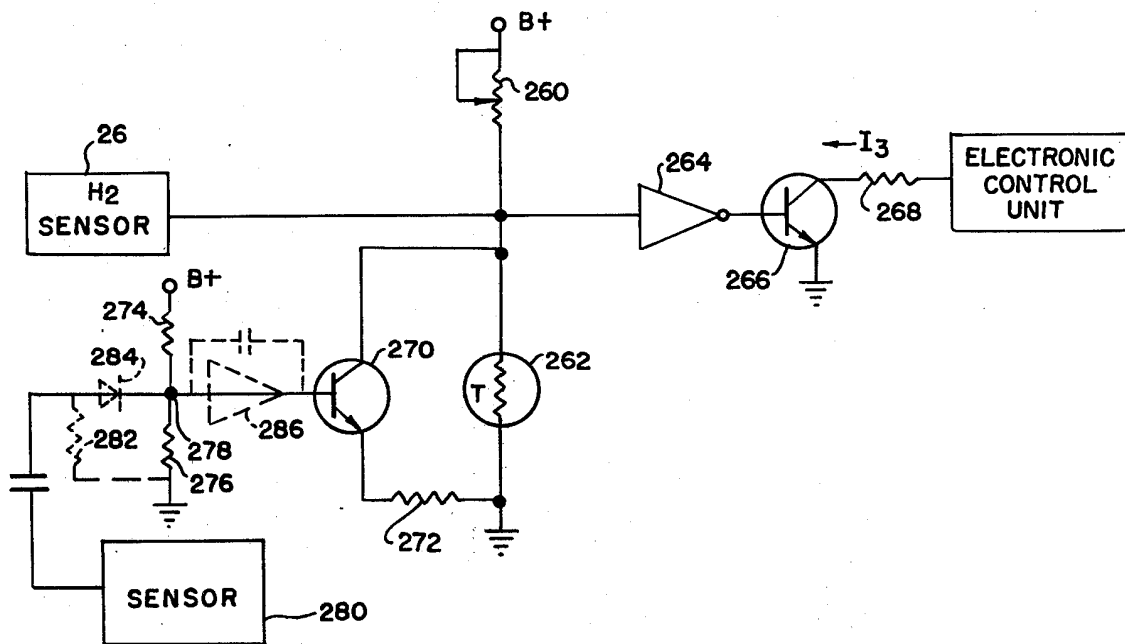
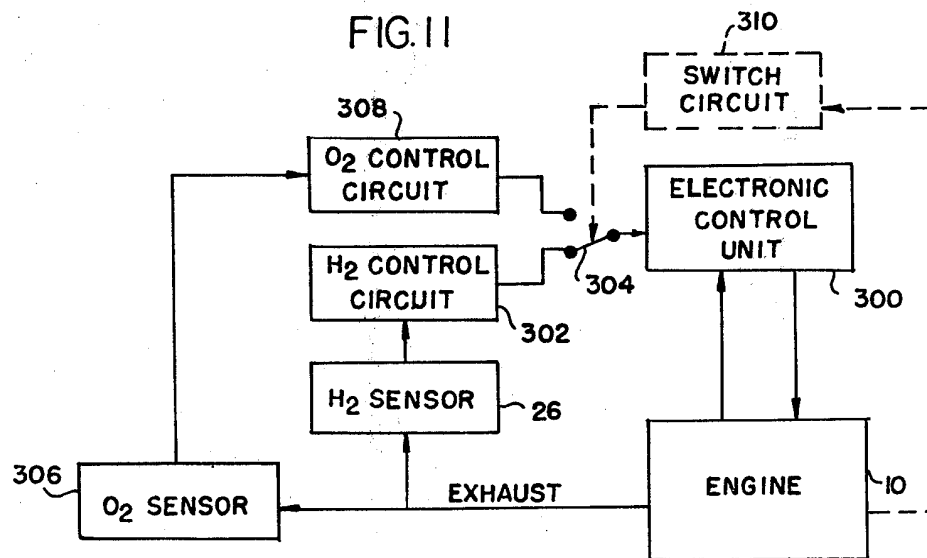


FIG. 11



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## CLOSED LOOP CONTROL SYSTEM FOR HYDROGEN FUELLED ENGINE

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The invention relates to fuel control systems and, in particular, to a closed loop fuel control system for an internal combustion engine using hydrogen as a fuel.

#### 2. Prior Art

Presently internal combustion engines use fossil or hydrocarbon type fuels. The world supply of fossil fuels, as we know, is limited and already the scientific community is looking at alternatives to the hydrocarbon fuels. Added to this, ecological problems stemming from the widespread use of hydrocarbon fuels is hastening the development of alternate relatively pollution-free alternates. One of the primary candidates as an alternate fuel is hydrogen, which is in abundant supply, and its by-product of combustion is water, which is not considered as a pollutant. Considerable research using hydrogen as a fuel is underway and operative engines using hydrogen as a fuel have been built and tested. The use of hydrogen as a fuel is taught by Billings in U.S. Pat. No. 3,983,882 (October 1976). This concept was also taught by A. F. Bush and W. D. Van Vorst in a paper presented at the Cryogenic Conference, Aug. 8-10, 1973 from Advances in Cryogenic Engineering Underwood in U.S. Pat. No. 3,862,624 (January 1975) and Smith in U.S. Pat. No. 3,608,529 (September 1971) also teach the use of hydrogen as a fuel. The hydrogen fuelled engine systems taught by the prior art cited above are open loop systems and must be periodically adjusted to assure optimum performance and optimum fuel economy.

The more advanced electronically controlled fossil fuel systems are tending towards closed loop systems in which the oxygen content of the exhaust is continuously monitored to provide a correction to the quantity of fuel being delivered to the engine to compensate for degradation, wear, or other changes in the engine's fuel/air delivery system, as well as for subtle changes in the operating characteristics of the engine. A typical example of one such closed loop electronically controlled fossil fuel system is taught by Seitz in U.S. Pat. No. 3,815,561 (June 1974).

The present invention is a closed loop electronic control system for a hydrogen fuelled engine using a sensor detecting the quantity of unburned hydrogen in the engine's exhaust.

### SUMMARY OF THE INVENTION

The invention is a closed loop fuel control system for a hydrogen fuelled engine using a sensor generating a feedback signal indicative of the quantity of unburned hydrogen in the exhaust gas emitted by the engine. The quantity of fuel delivered to the engine is electronically controlled in response to inputs indicative of the quantity of air being delivered, as well as other operating parameters of the engine. A hydrogen sensor monitors the composition of the exhaust gas, and generates a feedback signal indicative of the quantity of unburned hydrogen. The feedback signal is applied to the fuel delivery system and modifies the fuel being delivered to maintain a predetermined quantity of unburned hydrogen in the exhaust.

The object of the invention is a closed loop fuel control system for a hydrogen fuelled engine.

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Another object of the invention is a closed loop fuel control system for a hydrogen fuelled engine using a hydrogen sensor to detect the quantity of unburned hydrogen in the engine's exhaust.

Still another object of the invention is a closed loop fuel control system for a hydrogen fuelled engine in which the quantity of unburned hydrogen is maintained at a predetermined level.

Another object of the invention is a closed loop fuel control system for a hydrogen fuelled engine in which an enriched fuel mixture is provided during the transitional warm-up period.

These and other objects will become apparent from reading the detailed description of the preferred embodiment in conjunction with the drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the closed loop fuel control system for a hydrogen fuelled engine.

FIG. 2 is a first embodiment in which the feedback from the hydrogen sensor controls the pressure of the hydrogen fuel.

FIG. 3 is a second embodiment using an electronic control unit receiving inputs from a throttle position sensor and the hydrogen sensor.

FIG. 4 is a circuit diagram of the electronic unit of FIG. 3.

FIG. 5 is waveforms used in the description of the circuit diagram of FIG. 4.

FIG. 6 is a block diagram of the preferred embodiment of the closed loop fuel control system having an electronic control unit receiving inputs from engine sensors and the hydrogen sensor.

FIG. 7 is a schematic of the electronic control unit of FIG. 6.

FIG. 8 is waveforms used in the description of the schematic shown on FIG. 7.

FIG. 9 is a waveform used in the description of the operation of the feedback portion of the electronic control unit shown in FIG. 7.

FIG. 10 is an electrical schematic of an alternate embodiment providing for fuel enrichment during a transient mode of operation.

FIG. 11 is an alternate embodiment including an oxygen closed loop system to provide for lean operation under selected conditions.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

The basic concept of the closed loop fuel control system for a hydrogen fuelled engine is shown in FIG. 1. An engine 10 has an intake manifold 12 receiving a controlled quantity of air or oxygen from an external source through an air control valve 14 and a controlled quantity of hydrogen fuel through a fuel control valve 16. The exhaust gases generated by the engine 10 are emitted into an exhaust manifold 18 prior to being exhausted to the atmosphere. The air control valve 14 may be a typical butterfly valve, as used in contemporary automotive internal combustion engines, or may be of any other known configuration. The air control valve may be operator-actuated by means of a suitable control, such as the conventional accelerator foot pedal 20, or may be indirectly controlled by servo mechanisms responding to the signals generated by an electronic control unit, such as controller 22, as is well known in the art. Fuel delivery is controlled by a fuel control valve 16 in response to signals generated by

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controller 22. The controller 22 may receive inputs from the accelerator foot pedal 20, as well as engine sensors 24 generating signals indicative of the engine's operating parameters. The engine sensors 24 may comprise a mass air flow sensor generating a signal indicative of the quantity of air flow to the engine through the intake manifold or, alternatively, an engine speed sensor generating a signal indicative of the engine speed and an intake manifold pressure sensor, or any other sensor detecting an engine operating parameter which may be utilized in the controller for computing the amount of required fuel. The controller 22 also receives an input from a hydrogen sensor 26 detecting the quantity of hydrogen present in the exhaust gases in the exhaust manifold 18. The hydrogen sensor 26 may be of the type disclosed by C. C. Matle et al in U.S. Pat. No. 3,242,717 (March 1966). This sensor utilizes a palladium sensor film which changes its electrical conductivity upon exposure to hydrogens in an amount corresponding to the concentration of hydrogen passing over the palladium film.

The operation of the system is as follows: The controller 22 responds to the input from the operator through the accelerator pedal 20 and/or the engine's sensors 24 and generates a control signal indicative of the required quantity of hydrogen and/or air to be admitted into the engine, which actuates the hydrogen control valve 16 and/or air valve 14 to pass the computed quantity of hydrogen and air to the engine. The hydrogen/air mixture is burned in the engine to produce a desired mechanical motion, as in a conventional internal combustion engine, and the burned gases are emitted into the exhaust manifold. The hydrogen sensor detects the quantity of unconsumed hydrogen in the exhaust gases and generates a signal which corrects the signals generated by the fuel delivery controller 22 so that the quantity of unburned hydrogen in the exhaust gases has a predetermined value. As used herein, the term "air" includes the possibility of using relatively pure oxygen gas rather than atmosphere air as the oxidizing agent for the hydrogen fuel.

A simplified version of the closed loop hydrogen fuel control system is illustrated in FIG. 2. The system comprises an engine 10 having an intake manifold 12 and an exhaust manifold 18, as previously discussed with reference to FIG. 1. Air is emitted into the intake manifold via the air control valve illustrated as a butterfly valve 28 controlled by mechanical linkages from the operator's foot pedal control 20. The foot pedal 20 also actuates the hydrogen control valve 16 by suitable mechanical linkages to simultaneously provide a proportional quantity of hydrogen fuel to the engine. The hydrogen control valve 16 may be coordinated directly with the operation of the butterfly valve 28 or may be controlled through separate linkages. Hydrogen fuel from a hydrogen fuel storage 30 is communicated to the input of an electronically controlled pressure regulator 32. The output of the pressure regulator 32 is communicated to the input side of the hydrogen fuel control 16, as shown. The hydrogen content in the exhaust gas is monitored by the hydrogen sensor 26 which generates an output signal indicative of the concentration of hydrogen in the exhaust gas. A sum amplifier 34 combines the output signal from the hydrogen sensor with a set point signal generated by a set point generator illustrated as a variable potentiometer 36. The combined signal from the sum amplifier 34 is amplified in a buffer amplifier 36 prior to being communicated to the electronically con-

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trolled pressure regulator 22, which is operative to increase or decrease the pressure of the hydrogen gas being communicated to the input of control valve 16.

The operation of the embodiment shown in FIG. 2 is as follows: The position of the air control valve 14 and hydrogen control valve 16 are controlled directly by the actuation of the operator's pedal and, therefore, predetermined quantities of hydrogen and air are admitted to the engine's intake manifold. The hydrogen and air are mixed, then inhaled by the engine where the mixture is burned in a conventional manner to produce the desired mechanical motion. The burned exhaust gases are emitted into the exhaust manifold 18 wherein the hydrogen sensor 26 detects the concentration of unburned hydrogen and generates a signal indicative of the hydrogen concentration. This signal is negatively summed with the set point signal to produce a composite signal, which when amplified by the buffer amplifier 40, produces a signal controlling the pressure at the output of the pressure sensor 32. Since the quantity of hydrogen flowing through the fuel control valve 16 is a function of both the pressure differential across the fuel control valve and the input from the accelerator pedal 20 controlling the pressure effectively controls the quantity of fuel being delivered to the engine. When the detected quantity of hydrogen in the exhaust gas is less than the predetermined amount, the output of the hydrogen sensor 26 is indicative of the decrease in hydrogen content. Since the output of the hydrogen sensor has decreased, the output of the sum amplifier 36 increases. This signal, amplified by the buffer amplifier 40, causes the electronically controlled pressure regulator 32 to increase the pressure at the input end of the hydrogen valve 16 and the quantity of hydrogen input to the engine is increased. Conversely, when the hydrogen content in the exhaust gases is greater than the predetermined amount, the output of the hydrogen sensor 26 increases. This increased output of the hydrogen sensor, when negatively summed with the input from the set point generator 38 in the sum amplifier 36, results in a decreased signal which causes the electronically controlled pressure regulator to decrease the pressure at the input side of valve 16 and consequently decreasing the quantity of fuel delivered to the engine.

A slightly different embodiment of the closed loop hydrogen fuel control system is illustrated in FIG. 3. As in previous illustrations, the system comprises an engine 10 having an intake manifold 12 and an exhaust manifold 18. Air is emitted into the intake manifold via the air control valve 14 having a butterfly 28 controlled through mechanical linkages by the operator's foot pedal 20. The operator's foot pedal also actuates the movable contact of a potentiometer 42 and is shown to provide an electrical input to an electronic control unit 44. The electronic control unit 44 also receives an input from the hydrogen sensor 26 and generates an output signal which controls the actuation of hydrogen control valve 16. Hydrogen fuel from a hydrogen source 30 is received at the input of the hydrogen valve 16. The output of valve 16 is connected to the intake manifold via the valve 14.

The operation of the circuit is as follows: The air flow to the engine is controlled directly by the operator's foot pedal 20 which also controls the position of the movable contact of variable potentiometer 42 generating a first signal indicative of the quantity of air being supplied to the engine. The hydrogen sensor 26 generates a signal indicative of the hydrogen content of the

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gas in the exhaust manifold. The electronic control unit 44 responds to both of these signals and generates an output signal which controls the actuation of valve 16. When the hydrogen content of the exhaust gases is less than desired, the signal generated by the hydrogen sensor decreases. A decreased input from the hydrogen sensor causes the electronic control unit 44 to generate signals actuating valve 16 to increase the delivery of hydrogen gas to the engine. Conversely, when the hydrogen content of the exhaust gas is higher than the predetermined value, the increased output of the hydrogen sensor 26 causes the electronic control unit to generate output signals actuating hydrogen control valve 16 to decrease the delivery of hydrogen fuel to the engine.

The control unit 44 may take many forms. One embodiment of such a control unit capable of performing the desired functions is described with reference to the circuit diagram shown on FIG. 4 and the waveforms shown on FIG. 5. A sawtooth generator 100 generates a sawtooth wave 102 shown on FIG. 5 having a predetermined frequency and a predetermined peak to peak value. The sawtooth wave 102 is passed by a capacitance 104 to junction 106 of a bias control network comprising serially connected resistances 108, 110, and 112 connected between a source of electrical power designated B+ and ground. The B+ and ground symbols have their conventional meaning. A transistor 114 has its emitter connected to the junction between resistances 110 and 112 and its collector connected to ground. The base of transistor 114 receives the signal generated by the hydrogen sensor 26. The potentiometer 42 is shown to comprise serially connected variable resistance 118 and potentiometer 120 having a movable contact 122 actuated by the operator's foot pedal 20. Junction 106 and movable contact 122 are connected to the inputs of comparator 116 and the output of comparator 116 is connected to the base of an output transistor 124. The emitter of transistor 124 is connected directly to B+ and the collector is connected to ground through resistance 126 and to the output terminal 128.

The operation of the circuit is as follows: Considering first the operation when the output of the hydrogen sensor 26 is constant and indicative of the desired quantity of hydrogen in the exhaust gas, the output of the hydrogen sensor 26 applied to the base of transistor 114 causes transistor to conduct forming a parallel current path around resistance 112 effectively setting the bias potential at junction 106. The sawtooth waveform generated by the sawtooth generator 102 is passed by capacitance 104 and is applied to the positive input to comparator 116. The maximum and minimum peak values of the sawtooth wave at the input of the comparator, with reference to ground (0) potential, is determined by the value of the bias potential at junction 106. The output of the movable contact 122 of potentiometer is applied to the negative input of comparator 116. The output of the comparator 116 is a square wave, as shown on waveform B of FIG. 5. This square wave output of comparator 116, when applied to the base of transistor 124, produces a complementary square wave signal at the output terminal 128, as shown on waveform C of FIG. 5. The variable resistance 118 determines the minimum value of the signal at movable contact 122 when the operator's pedal 20 is in its rest or idle position and functions as an idle control. It is already seen that as the potential movable contact 122 increases in response to depressing the foot pedal 20, the

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width of the pulses at output terminal 128 increases. These pulses at output terminal 128 may control a simple ON-OFF hydrogen control valve 16 or a proportional control valve, as are known in the art.

When the hydrogen content of the exhaust gas increases, the output signal generated by the hydrogen sensor increases. This increased output signal applied to the base of transistor 114 decreasing its conduction and increasing the potential at junction 106. This effectively displaces the whole sawtooth wave in a positive direction. The positive portion of the square wave generated by the comparator 116 will increase and the positive portion of the square wave at the output terminal will decrease, resulting in a decrease in the quantity of hydrogen supplied to the engine by valve 16.

Conversely, if the hydrogen content of the exhaust gas decreases, the output of the hydrogen sensor will decrease, thereby increasing the conductance of transistor 114 and lowering the bias potential at junction 106. The sawtooth wave will be displaced downward towards ground and the positive portion of the square wave at the output terminal 128 will increase causing an increased fuel delivery to the engine. It would be evident to one skilled in the art that the control functions of embodiment shown on FIG. 3 could be reversed and that foot pedal 20 could directly control the actuation of hydrogen control valve 16. The signals generated by the electronic control unit 44 would then control the actuation of the air control valve 14.

A more sophisticated embodiment of the closed loop hydrogen fuel control system is illustrated in FIG. 6. An engine 10 having an intake manifold 12 and exhaust manifold 18 receives air or oxygen from an air control valve 14, such as butterfly valve 28 controlled in response to the actuation of an operator's accelerator pedal 20. Hydrogen fuel is supplied to the intake manifold from a regulated source of hydrogen 30 by means of electrically controlled valve 16 activated in response to signals from an electronic control unit 48. Control unit 48 also receives inputs from a pressure sensor 50, a speed sensor 52, a temperature sensor 54, and a hydrogen sensor 26. Electronic control unit 48 responds to these inputs and generates signals controlling the delivery of the hydrogen fuel to the engine. The control unit 48 may be embodied in an analog or digital form, as is known in the art.

The operation of the system is as follows: Air is emitted to the intake manifold by means of valve 14 under direct control of the operator by means of foot pedal 20. The electronic control unit, in response to the inputs from the pressure sensor, speed sensor and temperature sensor, compute the required amount of fuel required by the engine and generates a signal controlling the actuation of the electronically controlled valve 16. As previously discussed with reference to FIGS. 2 and 3, the hydrogen sensor detects concentration of hydrogen in the exhaust gases and generates a signal indicative of the hydrogen concentration in the exhaust manifold. The output of the hydrogen sensor 26 is applied to the control unit and modifies the signal generated in response to the pressure sensor, speed sensor and temperature sensor. When the quantity of hydrogen gas in the exhaust gas is less than the desired amount, the output of the hydrogen sensor causes the control unit 48 to increase the quantity of hydrogen being supplied to the engine. Alternatively, when the quantity of hydrogen in the exhaust gas is greater than the predetermined amount, the output of the hydrogen sensor causes the

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control unit 48 to decrease in the quantity of hydrogen being delivered to the engine.

In an alternate embodiment (not shown) the position of the foot pedal 20 may be indicative of a desired engine torque. In this embodiment, a signal indicative of the foot pedal is input directly into the control unit 48 and the control unit computes both the quantity of air and fuel to be admitted to the engine, as taught by Zech-nall in U.S. Pat. No. 3,750,632 (August 1973). Servo systems then control the actuation of both the air control valve 14 and the fuel control valve 16 in response to signals generated by the control unit. The output signal of the hydrogen sensor 26 may also be input to the control unit 48 to correct or trim the quantity of hydrogen fuel or air emitted to the engine, as discussed with reference to FIG. 6.

A circuit implementation of the control unit 48 of FIG. 6 is illustrated in FIG. 7. The basic electronic control unit 48, by way of example, is of the analog type disclosed by Reddy in U.S. Pat. No. 3,734,068, "Fuel Injection Control System". However, any other analog or digital control unit, including a microcomputer, may be used in conjunction with the hydrogen closed loop system, as previously indicated. The Reddy circuit shown is powered from a source of electrical energy designated at various points on the diagram as B+. The source of electrical power may be a battery or engine driven source, such as an alternator or generator conventionally associated with an internal combustion engine. The electronic control unit 48 has two capacitors 200 and 202 alternately charged by means of a pair of current sources 204 and 206 under the control of a switching network 210. The switching network receives engine speed data in the form of trigger signals at input terminals 212 and 214 from a timing circuit (not shown), synchronized with the rotation of the engine.

The pulse generating circuit comprises a discharge circuit 216 and a comparator circuit 218. The discharge circuit 216 also receives the timing signals from the timing circuit at input terminals 220 and 222, while the comparator circuit 218 receives a load signal at terminal 224, such as a signal from a pressure sensor generating a signal indicative of the pressure in the engine's air intake manifold. The comparator 218 generates an output pulse signal at terminal 226 indicative of the engine's fuel requirements in response to the potentials on capacitors 200 and 202 and the value of the pressure signal.

The operation of the electronic control unit is discussed with reference to FIG. 7 and the waveforms shown in FIG. 8. Current source 204 is a constant current source capable of charging capacitors 200 and 202 at a predetermined rate to a predetermined value indicated at point C on FIG. 8. Current source 206 is also a constant current source having a constant current output signal operative to charge capacitors 200 and 202 at a predetermined rate to potentials above the predetermined value of current source 204. The output of the speed sensor 52 are trigger signals TR1 and TR2 which are generated in timed sequence with the rotation of the engine. The trigger signals TR1 and TR2, in the form of two alternating square waves, as illustrated in FIG. 8, are respectively applied to input terminals 212 and 214 of switch 210 and control the sequential charging of the capacitors 200 and 202 by the two current sources 204 and 206. In the interval when the signal TR1 is positive and the signal TR2 is negative, or a ground potential, capacitor 202 is charged by current source 204 and capacitor 200 is charged by current source 206. When

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the trigger signals reverse polarity, the two capacitors are charged by the alternate current source.

The leading edges of the trigger signals TR1 and TR2, applied to the discharge circuit 216, activates a delay pulse generator 228, such as a single shot multivibrator which generates a delay pulse "p" having a predetermined pulse width significantly shorter than pulse width of the trigger pulse. A positive trigger signal on input terminal 220 coincident with the positive delay pulse signal "p" removes the effective ground potential on the base of transistor 230 causing it and transistor 232 to conduct. Transistor 232 discharges capacitor 202 to near ground potential during the period of the delay pulse. Termination of the delay pulse returns a ground potential at the output of the delay pulse generator 228 which is applied to the base of transistor 230 through diode 234. The ground signal at its base blocks transistor 230 which in turn blocks transistor 232 permitting capacitor 202 to be charged by current source 204 to the predetermined value. When the trigger signals TR1 and TR2 change polarity, a positive potential is applied to terminal 222 and the delay pulse "p" permits the base of transistor 236 to be forward biased and capacitor 200 is discharged by means of transistor 238 in a manner equivalent to the way capacitor 202 was discharged. The switching network 210 also changes state in response to the inversion of the trigger signals and capacitor 202 is charged from current source 206 and capacitor 200 is charged from current source 204.

The pressure signal from pressure sensor 50 is applied to pressure input terminal 224 and forward biases transistor 242 which in turn forward biases transistor 244. The conductance of transistor 244 produces a positive potential at output terminal 226 which is connected to the junction between resistances 246 and 248 forming a voltage divider network between the collector of transistor 244 and ground. The conductance of transistor 242 also biases the emitter of transistor 250 to a potential approximately equal to the value of the pressure signal appearing at terminal 224. The charge signals on capacitor 200 and 202 are applied to the base of transistor 250 through diodes 252 and 254, respectively. When the signals on both capacitors have a potential value below the value of the pressure signal, transistor 250 is blocked. However, when the potential value on either capacitor 200, 202 or both, exceed the value of the pressure signal, transistor 250 conducts. Conductance of transistor 250 raises the value of the potential appearing at the emitter of transistor 242 above the value of the pressure signal applied to its base thereby blocking transistor 242. Blocking of transistor 242 blocks transistor 244 and with transistor 244 in the blocked state, the potential at output terminal 226 assumes a ground potential terminating the output signal.

The voltage waveforms generated across capacitors 200 and 202 in response to a series of trigger signals TR1 and TR2 and the delayed pulse "p" are shown in FIG. 8. The decreasing period of the sequential trigger signals illustrated is an exaggerated example of the change in the pulse width of the trigger signals as a function of engine speed. Referring to the waveform for capacitor 202, the initial segment from A to B is generated when TR1 is positive and the delay pulse generating circuit is producing a delay pulse "p" discharging capacitor 202. Upon termination of the delay pulse "p", point B, capacitor 202 begins to charge at a rate determined by current source 204 to its predetermined value indicated as point C. The charge on capacitor 202 remains at the

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predetermined value indicated as point C. The charge on capacitor 202 remains at the predetermined value for the remainder of the positive portion of the trigger signal TR1. At point D, the trigger signals TR1 and TR2 reverse polarity and capacitor 202 is now charged by the current source 206 during the interval from D to E which is equal to the interval when the trigger pulse TR2 is positive.

When the charge on either capacitor 200 or 202 reaches the value of the signal applied to the emitter of transistor 250, point F, the signal at the output terminal 226 is a ground potential. At the occurrence of a trigger signal, the capacitor which was being charged by current source 206 is discharged to approximately ground potential by the discharge circuit 216 and the charge on the capacitor being charged by current source 204 is below the value of the signal applied to the emitter of the transistor 250, which is indicative of the value of the pressure signal. Since the charge on both capacitors is below the value of the pressure signal, transistor 250 is blocked, which renders transistors 242 and 244 conductive generating a positive signal at output terminal 226 having a value determined by the respective value of resistances 246 and 248. The signal at output terminal 226 remains positive until the charge on the capacitor being charged by current source 206 exceeds the value of the pressure signal. When the charge on the capacitor exceeds the value of the pressure signal, point F, on the segment DE, transistors 242 and 244 become blocked and the signal at the output terminal 226 returns to ground potential. The time interval, when the signal at output terminal 226 is positive, is indicative of the engine's fuel requirements as a function of engine speed and the pressure in the intake manifold.

Referring back to FIG. 7, the circuit details of the closed loop portion of the circuit will be discussed. The hydrogen sensor 26 detects the partial pressure of hydrogen in the exhaust gas and generates an output signal. This signal is summed with the output of the set point generator comprising variable resistance 260 and the temperature sensor 54 illustrated as positive temperature coefficient resistor 262 connected between B+ and ground. One skilled in the art will recognize that other types of temperature sensors, such as a thermistor, could be used with appropriate changes to the circuit without departing from the set point concept. The sum signal is input to amplifier 40 which in this particular circuit is an inverter amplifier 264. The output of the inverter amplifier 264 is applied to the base of transistor 266. The collector of transistor 266 is connected to the output of constant current source 206, through resistance 268.

The operation of this circuit will now be discussed under various operating conditions. First, it is assumed that the engine is at its normal operating temperature and the hydrogen content of the exhaust gas is at its predetermined value. The sum of the output from the hydrogen sensor 26 and the set point generator is input to the inverter amplifier which generates an output signal applied to the base of transistor. This places transistor 266 in a partial conductive state, which through resistance 268, sinks a predetermined portion  $I_3$  of the current  $I_2$  from current output source 206.

Referring now to FIG. 9, when the hydrogen content of the exhaust gas is at its predetermined level, capacitors 200 and 202 are charged at a rate during the second interval indicated by the solid line 270. The charging current is the output current  $I_2$  of constant current

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source 206 minus the current  $I_3$  drained by transistor 266.

If the hydrogen content of the exhaust increased, indicative that the control system is inputting excessive hydrogen fuel to the engine, the output of the hydrogen sensor increases and the output of inverter amplifier decreases. The decreased output of the inverter amplifier 264 decreases the amount of current  $I_3$  being drained from the constant current source 206 by transistor 266. This causes capacitances 200 and 202 to be charged at a faster rate, as indicated by dashed line 272 decreasing the pulse widths of the injection pulses thereby decreasing the quantity of hydrogen being supplied to the engine.

If the hydrogen content of the exhaust decreases, the output of the hydrogen sensor 26 decreases, and the output of the inverter amplifier 264 increases. This increases the conductance of transistor 266. Drain current  $I_3$  flowing through transistor 266 increases, which decreases charging current  $I_2$  thereby decreasing the rate at which capacitances 200 and 202 are charged, as indicated by line 274 on FIG. 9. Decreasing the charging rate of capacitances 200 and 202 increases the pulse width of the injection pulses, increasing the quantity of fuel being supplied to the engine, as required.

Immediately after starting a cold engine, it is desirable to operate the engine with a rich air/fuel mixture until the engine reaches a nominal operating temperature. This function may be provided by including a separate drain circuit, draining a portion of the output current  $I_2$  of the constant current source 206 or may be included in the set point generator, as shown. The advantage of this latter approach shall be explained hereinafter. The temperature sensor 54, shown as a positive temperature coefficient (PTC) resistance 262, has a resistance value which is a direct function of the engine temperature. When the engine is cold, the resistance of thermistor 262 is low, decreasing the output potential of the set point generator 36 which effectively increases the bias at base of transistor 266. This increases the drain current through transistor 266 and decreases the rate at which capacitances 200 and 202 are charged by source 206. The excess hydrogen is sensed by the  $H_2$  sensor which causes an increase in the output of the  $H_2$  sensor. By appropriate selection of resistance 260 and PTC resistor 262, the combined signals of the set point generator and the hydrogen sensor can be made to appear at the input of inverter amplifier 264, as if the engine was operating at its normal operating temperature and the hydrogen content of the exhaust gas was lower than the predetermining quantity, therefore, the desired warm-up enrichment is achieved.

As an alternative to the pulse width modulation control system as discussed with reference to FIG. 7, the injection signal generated by the control unit 48 may be pulse division modulated, as described in "Reference Data for Radio Engineers", Howard Sams & Co., 6th edition, 1975, pp. 23-13 through 23-19.

A further embodiment of the closed loop portion of the circuit shown on FIG. 7 to provide for acceleration enrichment is illustrated on FIG. 10. Since the basic portion of the control unit 48 is the same as shown on FIG. 7, its details are not repeated. As in FIG. 7, the circuit comprises the temperature sensor 26, the set point generator consisting of variable resistance 260 and positive temperature coefficient resistance 262, inverter amplifier 264, transistor 266 and resistance 268. In this embodiment a transistor 270 and resistance 272 are con-



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nected in parallel with the PTC resistance 262. The base of transistor 270 is connected to the junction 278 between resistances 274 and 276 which form a voltage divider between B+ and ground potential. The output of a sensor 270 indicative of a change in the engine's mode of operation is communicated to junction 278 through a capacitance 282. The sensor 270 may be the pressure sensor 50 or a throttle sensor sensing the position or movement of the throttle as is well known in the art.

The operation of this embodiment is as follows: When the output of the sensor 280 is zero or a constant value, the current flow through transistor 270 is controlled by the bias potential applied to its base by the voltage divider comprising resistances 274 and 276 and the voltage drop across resistance 272. The set point potential at the junction between resistance 260 and the parallel connected PTC resistance and transistor 270 is the desired nominal value for the proper operation of the circuit, as described with reference to the circuit shown on FIG. 7.

When a change in the engine's mode of operation is commanded, the output of sensor 280 changes. This changing output signal is passed by capacitance 282 and applied to the base of transistor 270. When the change is indicative of a demand for acceleration, the potential at the base of transistor 270 is increased, increasing the conductivity of the transistor and lowering the potential at the junction of the set point generator. This in turn increases the conductivity of transistor 266, which as previously described, increases the duration of the injection pulses generated by the electronic control unit.

If the change is indicative of a demand for deceleration, the current flow through transistor 270 decreases effectively raising the potential at the junction of the set point generator and the length of the injection pulses is decreased.

As previously discussed with reference to FIG. 7, the hydrogen sensor maintains limited control over the circuit during the transient modes of operation.

If only fuel enrichment during acceleration is desired, a resistance 282 and diode 284, shown in phantom, may be added as shown. Also, if it is desired to increase the period of fuel enrichment, an integrator such as integrator 286, shown in phantom, may be added. These, as well as other techniques well known in the art, may be used to modify the signal from sensor 270 to meet the fuel requirements of the engine during transient conditions.

Another embodiment of the invention is illustrated in FIG. 11. This embodiment further includes an oxygen closed loop fuel control system such as taught by Seitz in U.S. Pat. No. 3,815,561, "Closed Loop Engine Control System" (June 1974), which permits the engine to be operated with a lean (oxygen rich) air/fuel mixture rather than the hydrogen rich air/fuel mixture taught in the previous embodiments. This embodiment has the advantage that when the engine load is light and not subject to frequent change such as when driving on an open highway or a freeway in contrast to stop and start city conditions, the system may be switched from the rich hydrogen closed loop system to the lean oxygen closed loop system. The switching may be accomplished manually by the operator or automatically in response to predetermined engine operating conditions, such as engine speed, manifold pressure, throttle position, or any other.

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Referring now to FIG. 11, the fuel supply to the engine 10 is controlled by an electronic control unit 300 in response to one or more of the engine's operation parameters. The hydrogen sensor 26 sensing the engine's exhaust operates as previously described and inputs a signal indicative of the exhaust hydrogen content into a hydrogen control circuit 302, which in turn generates a signal which is communicated to the electronic control unit 300 through a switch 304. This closed loop system may be of the type discussed with reference to FIG. 6. In a like manner, an oxygen sensor 306 generates a signal indicative of the oxygen content of the engine's exhaust which is communicated to an oxygen control circuit 308. The oxygen control unit in turn generates a signal which is communicated to the electronic control unit 300 through switch 304. The oxygen closed loop system may be identical to that disclosed in the Seitz patent cited above, or any other oxygen closed loop system known in the art.

The position of switch 304 determines whether the output signals generated by the electronic control unit 300 will be corrected or trimmed by the output of the hydrogen control circuit 302 or the oxygen control circuit 308. Switch 304 may be a manual operator actuated switch or a switch actuated in response to predetermined engine operation parameters. For example, switch 304 may be a mechanical or a solid state switch activated in response to the output of a switch circuit 310 shown in phantom. The switch circuit may receive a signal indicative of the engine speed and a signal indicative of the dynamic state of the pressure in the engine's intake manifold. The circuit 310 may be operative to produce a signal first activating switch 304 to apply the signal generated by the hydrogen control circuit 302 to the electronic control unit 300 when the engine speed is below a predetermined speed and operative to generate a second signal activating switch 304 to apply the output of oxygen control circuit 304 to the electronic control unit 300, when the engine speed is above the predetermined speed and the manifold pressure is not changing indicating the absence of an acceleration condition. As is well known, other signals may be used in place of the speed and the pressure signals to indicate a steady high speed mode of operation, such as would be encountered during open highway or expressway driving conditions. This may also be done digitally by counting a predetermined number of injection pulses having nearly identical pulse widths or pulse intervals.

Having described the closed loop hydrogen control system with respect to several different embodiments, it is not intended that the invention be limited to those discussed and illustrated in the drawings. It is recognized that a person skilled in the art will be able to devise alternate embodiments without departing from the spirit of the invention.

What is claimed is:

1. A closed loop fuel control system for a hydrogen fuelled engine having a source of hydrogen fuel comprising:

air control means for controlling the quantity of air being delivered to the engine in response to the command of an operator;

means for generating an air quantity signal indicative of the quantity of air being delivered to the engine;

means for generating a hydrogen feedback signal having a value indicative of the concentration of unburned hydrogen in the residue of the engine's combustion process emitted as an exhaust gas; and

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fuel control means for controlling the quantity of hydrogen being delivered to the engine from the hydrogen source in response to said air quantity signal and said hydrogen feedback signal to provide a combustible mixture of air and hydrogen having a predetermined concentration of unburned hydrogen in said exhaust gas.

2. The fuel control system of claim 1 wherein said fuel control means comprises:

electrically controlled pressure regulator means having an input receiving hydrogen fuel from said source and an output for delivering said hydrogen fuel at a pressure controlled by the value of said feedback signal; and

mechanically actuated valve means receiving hydrogen fuel from the output of said pressure regulator means for controlling the quantity of hydrogen fuel delivered to said engine;

and wherein said means for generating an air quantity signal is means for linking the operator's command to said air control means to said mechanically actuated valve means, said means for linking operative to open and close said valve as a function of the commanded quantity of air being delivered to the engine.

3. The fuel control system of claim 1 wherein said means for generating an air quantity signal is a means actuated by said air control means for generating an electrical signal indicative of the commanded quantity of air being delivered to the engine;

and wherein said fuel control means comprises:

circuit means for combining said electrical signal with said hydrogen feedback signal to generate a composite signal indicative of the engine's fuel requirements; and

electromechanical valve means disposed between said engine and said source of hydrogen fuel for controlling the quantity of hydrogen fuel delivered to the engine in response to said composite signal.

4. The fuel control system of claim 1 wherein said engine includes engine sensors generating signals indicative of the engine's operating parameters including said means for generating an air quantity signal, said fuel control means comprises means for generating fuel control signals indicative of the engine's fuel requirements in response to said signals indicative of the engine's operating parameters and said hydrogen feedback signal; and

valve means disposed between said source of hydrogen fuel and said engine for controlling the quantity of fuel delivered to the engine in response to said fuel control signals.

5. The fuel control system of claim 4 wherein said fuel control signals are pulse width modulated signals and said valve means is at least one ON-OFF valve opening and closing in response to said pulse width modulated signals.

6. The fuel control system of claim 5 wherein said at least one ON-OFF valve is a plurality of ON-OFF valves.

7. The fuel control system of claim 4 wherein said valve means is a proportional valve delivering a continuous quantity of fuel to the engine at a rate proportional to said fuel control signals.

8. The fuel control system of claim 4 wherein said engine includes an air intake manifold and said air control means is a throttle valve controlling the air flow

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through said intake manifold, said means for generating an air quantity signal comprises:

a pressure sensor for generating a pressure signal indicative of pressure in said intake manifold; and a speed sensor for generating a speed signal indicative of the engine speed; and

wherein said fuel control means generates said fuel control signals in response to said pressure signal, said speed signal and said hydrogen feedback signal.

9. The fuel control system of claim 8 wherein said engine has a nominal operating temperature and said engine sensors further includes a temperature sensor generating temperature signals indicative of the engine's temperature, said fuel control means is further responsive to said temperature signal to generate fuel control signals providing an enriched air/fuel mixture to the engine when the engine's temperature is below its nominal operating temperature, said air/fuel mixture being enriched as an inverse function of the engine's temperature.

10. The fuel control system of claim 1 wherein said fuel control means further includes:

transient mode means for changing the quantity of fuel delivered to the engine by said fuel control means in response to a transient mode signal indicative of a change in the operating mode of the engine; and

means for generating said transient mode signal in response to at least one operating parameter of the engine.

11. The fuel control system of claim 10 wherein said means for generating said transient mode signal is said means for generating an air quantity signal.

12. The fuel control system of claim 1 wherein said system further includes:

means for generating an oxygen feedback signal indicative of the concentration of unconsumed oxygen in the residue of the engine's combustion process; and

switch means for controlling the response of said fuel control means between said hydrogen feedback signal and said oxygen feedback signal;

wherein said fuel control means provides a hydrogen rich air/fuel mixture to the engine in response to said hydrogen feedback signal and an oxygen rich air/fuel mixture to the engine in response to said oxygen feedback signal.

13. The closed loop system of claim 12 wherein said switch means is an operator actuated manual switch.

14. The closed loop system of claim 12 wherein said switch means comprises:

a switch selectively interconnecting said means for generating a hydrogen feedback signal and said means for generating an oxygen feedback signal with said fuel control means in response to a switch signal; and

means for generating said switch signal in response to at least one engine operating parameter indicative of the operating mode of the engine.

15. A closed loop fuel control system for a hydrogen fuelled engine, wherein said engine includes a source of hydrogen fuel and an engine control, the position of which is indicative of a commanded engine torque, comprising:

means for generating a hydrogen feedback signal having a value indicative of the concentration of

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unburned hydrogen in the residue of the engine's combustion process emitted as an exhaust gas; and means for controlling the quantity of hydrogen and an oxidizing agent delivered to the engine in response to the position of said engine control and said hydrogen feedback signal to cause the engine to generate the commanded torque with the exhaust gas having a predetermined quantity of unburned hydrogen.

16. The control system of claim 15 wherein said oxidizing agent is air.

17. The control system of claim 15 wherein said oxidizing agent is oxygen.

18. The fuel control system of claim 15 wherein said control means comprises:

means mechanically actuated by said engine control for controlling the quantity of fuel being delivered to the engine;

means for generating a hydrogen signal indicative of the quantity of hydrogen being delivered to the engine;

oxidizer control means for controlling the quantity of oxidizing agent being delivered to the engine in response to said hydrogen signal and said hydrogen feedback signal.

19. The system of claim 15 wherein said control means comprises:

oxidizer control means mechanically actuated by said engine control for controlling the quantity of said oxidizing agent being delivered to the engine;

means for generating an oxidizer quantity signal indicative of the quantity of the oxidizing agent being delivered to the engine; and

fuel control means for controlling the quantity of hydrogen being delivered to the engine in response to said oxidizer quantity signal and said hydrogen feedback signal.

20. The fuel control system of claim 19 wherein said fuel control means comprises:

electrically controlled pressure regulator means having an input receiving hydrogen fuel from said source and an output for delivering said hydrogen fuel at a pressure controlled by the value of said feedback signal; and

mechanically actuated valve means receiving hydrogen fuel from the output of said pressure regulator means for controlling the quantity of hydrogen fuel delivered to said engine;

and wherein said means for generating an oxidizer quantity signal is means for linking the operator's command to said oxidizer control means to said mechanically actuated valve means, said means for linking operative to open and close said valve as a function of the commanded quantity of oxidizing agent being delivered to the engine.

21. The fuel control system of claim 20 wherein said means for generating an oxidizer quantity signal is a means actuated by said oxidizer control means for generating an electrical signal indicative of the commanded quantity of oxidizing agent being delivered to the engine;

and wherein said fuel control means comprises:

circuit means for combining said electrical signal with said feedback signal to generate a composite signal indicative of the engine's fuel requirements; and

electromechanical valve means disposed between said engine and said source of hydrogen fuel for

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controlling the quantity of hydrogen fuel delivered to the engine in response to said composite signal.

22. The fuel control system of claim 19 wherein said engine includes engine sensors generating signals indicative of the engine's operating parameters including said means for generating an oxidizer quantity signal, said fuel control means comprises means for generating fuel control signals indicative of the engine's fuel requirements in response to said signals indicative of the engine's operating parameters and said feedback signal; and

valve means disposed between said source of hydrogen fuel and said engine for controlling the quantity of fuel delivered to the engine in response to said fuel control signals.

23. The fuel control system of claim 22 wherein said fuel control signals are pulse width modulated signals and said valve means is at least one ON-OFF valve opening and closing in response to said pulse width modulated signals.

24. The fuel control system of claim 23 wherein said at least one ON-OFF valve is a plurality of ON-OFF valves.

25. The fuel control system of claim 22 wherein said valve means is a proportional valve delivering a continuous quantity of fuel to the engine at a rate proportional to said fuel control signals.

26. The fuel control system of claim 22 wherein said fuel control signals are pulse position modulated, and said valve means delivers a quantity of hydrogen proportional to said pulse position modulated signals.

27. The fuel control system of claim 22 wherein said engine includes an intake manifold and said oxidizer control means is a throttle valve controlling the oxidizing agent's flow through said intake manifold, said means for generating an oxidizer quantity signal comprises:

a pressure sensor for generating a pressure signal indicative of pressure in said intake manifold; and a speed sensor for generating a speed signal indicative of the engine speed; and

wherein said fuel control means generates said fuel control signals in response to said pressure signal, said speed signal and said feedback signal.

28. The fuel control system of claim 27 wherein said engine has a nominal operating temperature and said engine sensors further includes a temperature sensor generating temperature signals indicative of the engine's temperature, said fuel control means is further responsive to said temperature signal to generate fuel control signals providing an enriched oxidizing agent fuel mixture to the engine when the engine's temperature is below its nominal operating temperature, said oxidizing agent fuel mixture being enriched as an inverse function of the engine's temperature.

29. The fuel control system of claim 19 wherein said control means further includes:

transient mode means for changing the quantity of hydrogen and oxidizing agent delivered to the engine by said control means in response to a transient mode signal indicative of a change in the operating mode of the engine; and

means for generating said transient mode signal in response to at least one operating parameter of the engine.

30. The fuel control system of claim 29 wherein said means for generating said transient mode signal is said means for generating an oxidizer quantity signal.

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31. The fuel control system of claim 14 wherein said oxidizing agent includes oxygen as one of its constituents, said system further includes:

means for generating an oxygen feedback signal indicative of the concentration of oxygen in the residue of the engine's combustion process; and  
switch means for controlling the response of said fuel control means between said hydrogen feedback signal and said oxygen feedback signal;  
wherein said fuel control means provides a hydrogen rich fuel mixture to the engine in response to said hydrogen feedback signal and an oxygen rich fuel

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mixture to the engine in response to said oxygen feedback signal.

32. The closed loop system of claim 31 wherein said switch means is an operator actuated manual switch.

33. The closed loop system of claim 31 wherein said switch means comprises:

a switch for selectively connecting said means for generating a hydrogen feedback signal and said means for generating an oxygen feedback signal with said fuel control means in response to a switch signal; and

means for generating said switch signal in response to at least one engine operating parameter indicative of the operating mode of the engine.

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**United States Patent** [19]**Shaffer, Jr.**[11] **4,161,657**[45] **Jul. 17, 1979****[54] HYDROGEN SUPPLY AND UTILITY SYSTEMS AND COMPONENTS THEREOF****[76] Inventor:** Marlin R. Shaffer, Jr., 1957 Hubbard Ave., Salt Lake City, Utah 84108**[21] Appl. No.:** 885,584**[22] Filed:** Mar. 13, 1978**Related U.S. Application Data****[63]** Continuation of Ser. No. 551,763, Feb. 21, 1975, abandoned.**[51] Int. Cl.<sup>2</sup>** ..... F03G 7/02**[52] U.S. Cl.** ..... 290/1 R; 60/641**[58] Field of Search** ..... 290/1 R; 204/129, 278; 423/359; 60/641**References Cited****U.S. PATENT DOCUMENTS**

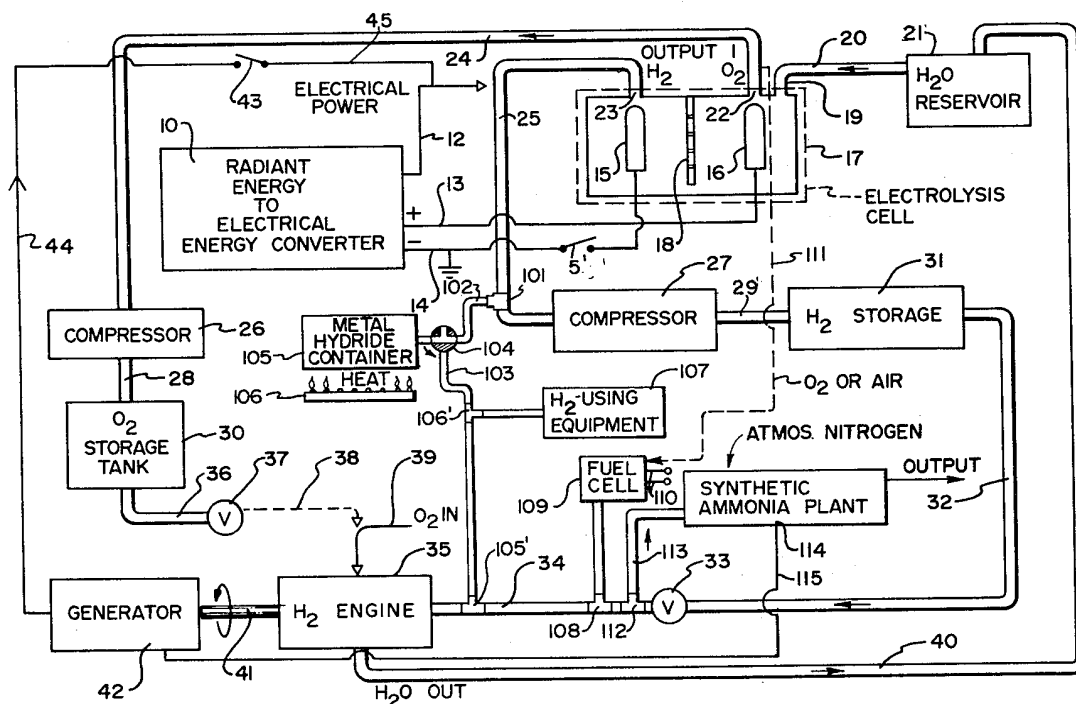
1,862,224	6/1932	Langley	204/278
2,036,613	4/1936	Stuart	290/1 R
3,459,953	8/1969	Hughes et al.	204/129 X
3,484,617	12/1969	Winsel	290/1 R
3,928,145	12/1975	Othmer	60/641 X
3,965,683	6/1976	Dix	60/641

**FOREIGN PATENT DOCUMENTS**

15031	5/1924	Netherlands	423/359
149556	8/1920	United Kingdom	204/278

**Primary Examiner**—Gene Z. Rubinson**Assistant Examiner**—W. E. Duncanson, Jr.**[57] ABSTRACT**

An energy system that is responsive to and converts radiant energy into direct current electricity at a pair of output connectors which are maintained at a potential difference. The hydrogen and oxygen-generating electrodes of an electrolysis cell are coupled to such terminals so that hydrogen and oxygen may be produced, with at least the former being stored under pressure. Valve or regulator means is supplied the hydrogen storage system such that, preferably, a constant volumetric output over a given time span is maintained for producing a useful result such as a continuous source of electrical energy. The valve means is regulated so that the gas pressure within the storage system is always maintained above a predetermined threshold. Useful results are produced in the form of mechanical power, electrical power, the synthesizing of ammonia, and other important products and results. Where a hydrogen engine is employed in the system, then the vapor output is preferably fed back to the electrolysis cells of the system so that the water needed in the cell is continuously replenished. The system is designed such that the radiant energy, though intermittent or irregular, will generate a regulated source of essentially uniform electrical or mechanical energy or other useful, continuous product or result, as desired.

**5 Claims, 10 Drawing Figures**

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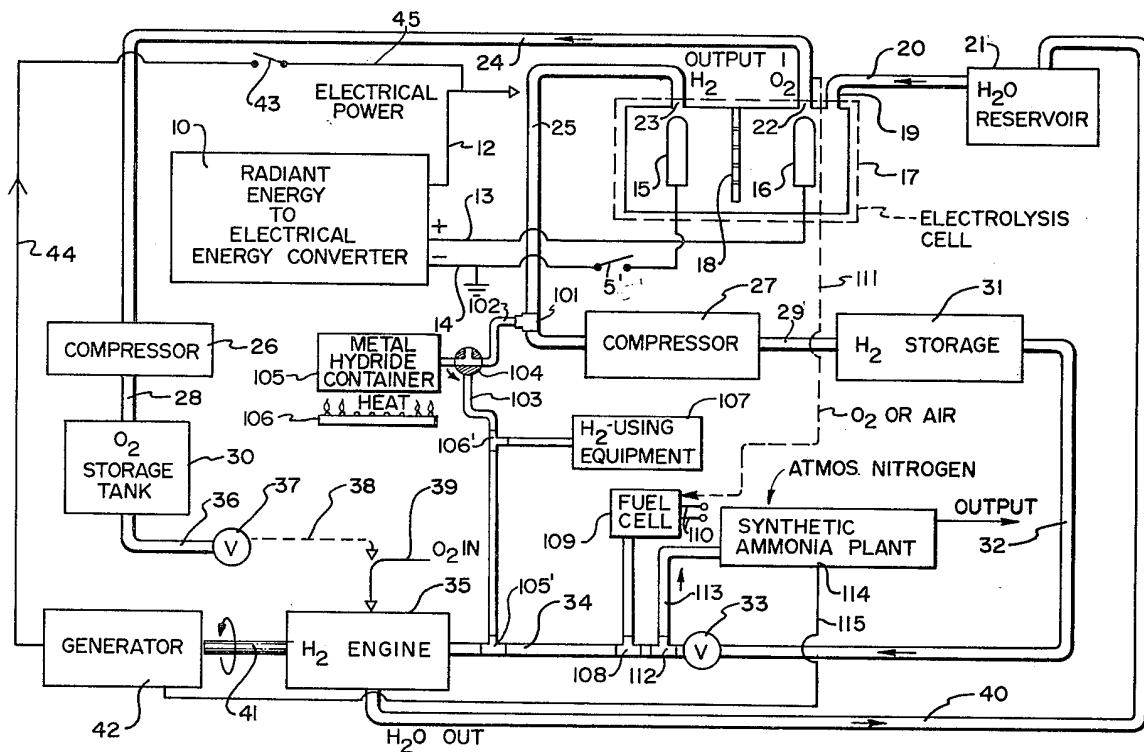


FIG. 1

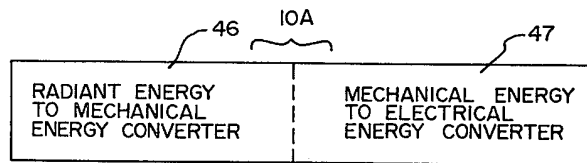


FIG. 3

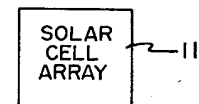


FIG. 2

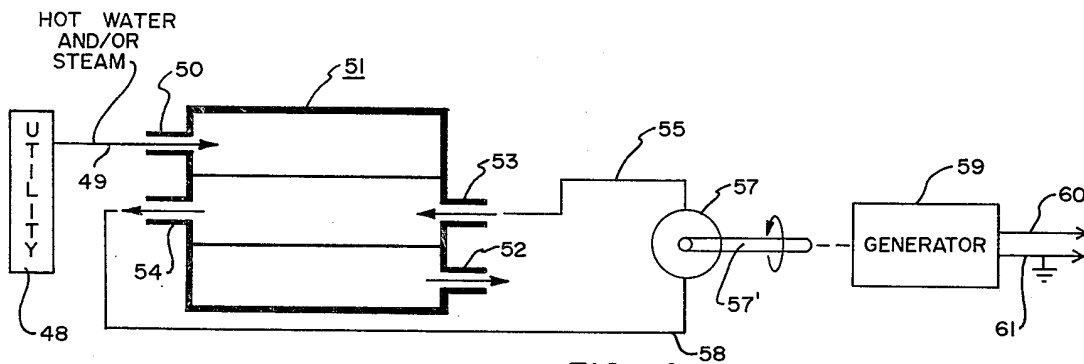
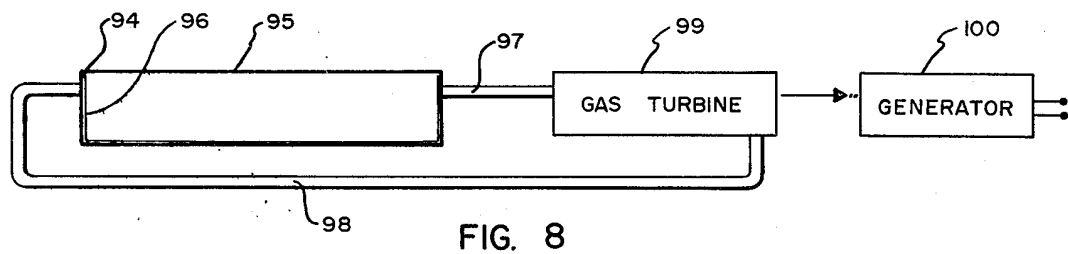
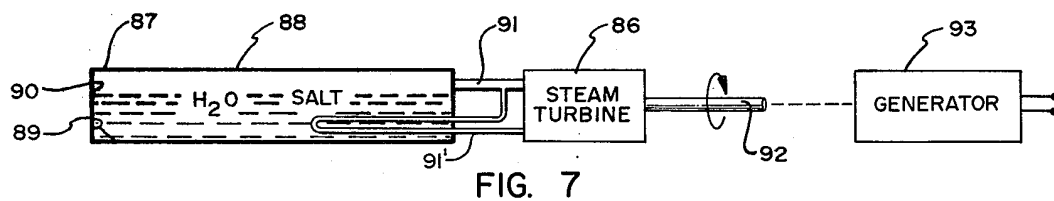
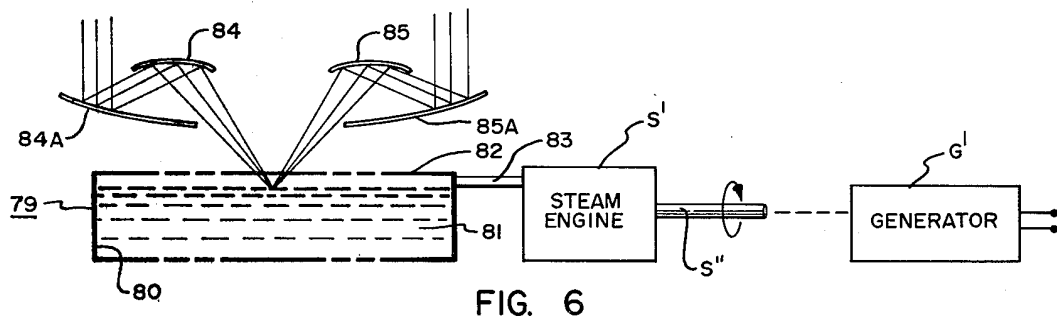
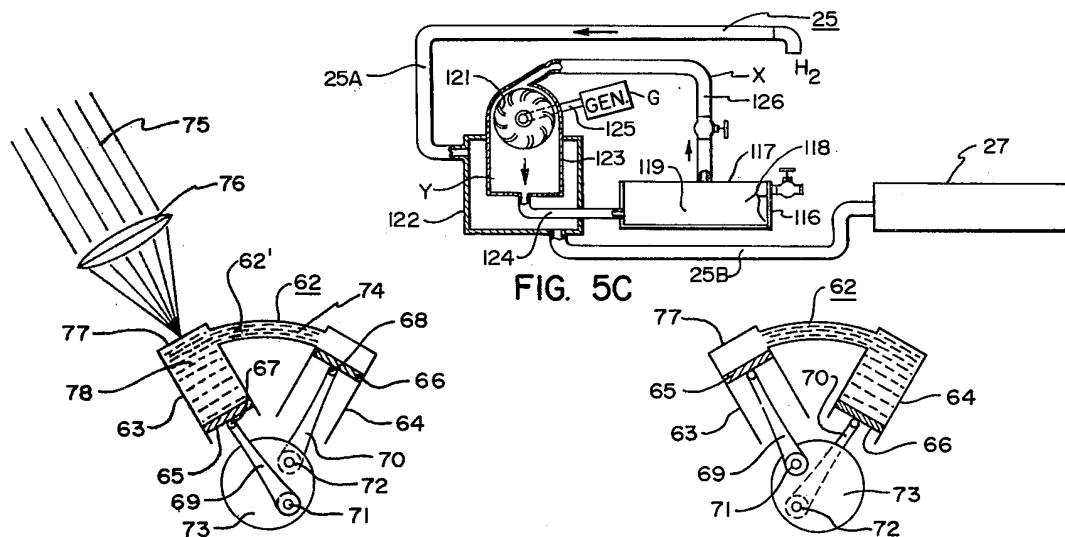


FIG. 4

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# HYDROGEN SUPPLY AND UTILITY SYSTEMS AND COMPONENTS THEREOF

This is a continuation, of application Ser. No. 551,763, filed Feb. 21, 1975 now abandoned.

The present invention relates to energy systems, and, more particularly, to a new and improved energy system incorporating the features of the production and storage under pressure of hydrogen, for a variety of uses and systems.

The term "radiation" as used herein is employed in its broadest sense to include radiant light and heat energies. This will include solar energy from the sun, or heat-exchanger employment with geothermal steam and utility power plant hot water and steam, and so forth.

Of primary but not exclusive importance, is the concept of solar energy and its utilization herein. Solar energy by its very nature is variable, and this not only because of the earth's seasons and the change in the angle of the incidence of light rays relative to the earth's surface, but also by virtue of changing weather conditions, dust, storms, and so forth. The intermittent nature of solar energy is a difficult problem with which to deal, particularly where dependable and continuous sources of energy and power are required.

In the present invention, means are provided to convert directly or step-by-step the radiant energy received into an electrical potential difference, which potential difference is applied across the electrodes of an electrolysis cell. The cell will contain pure water having as an electrolyte sodium hydroxide or potassium hydroxide, by way of example. These electrolytes are ideal because they are not destroyed nor need they be replenished during operation of the cell. The purpose for use of the electrolytic cell to produce hydrogen that can be maintained in a storage device for long periods of time. Thus, even though the electrolysis action may take place intermittently, yet the hydrogen can be used as fuel or other source so that a regulated supply of hydrogen in uniform flow can be routed to a hydrogen engine or to another device or process. The intermittent character of the radiant energy, therefore, has no effect on the regulated output desired.

In the radiant-energy to electrical-energy converter employed in the invention, a solar cell array is ideally suited. However, a two-step process may be included wherein radiant energy is first converted to mechanical energy, and then the mechanical energy is converted to electrical energy. The latter two-step system might include a heat engine and dynamo or generator combination, or similar apparatus.

With employment of the electrolytic cell and the resultant high volumetric supply of hydrogen produced, the hydrogen therefrom can be used to operate a fuel cell, to synthesize ammonia with atmospheric nitrogen under the Haber or other process, can be stored in super-cooled or metal-hydride tanks, and so forth.

Also contemplated is the use of geothermal or electric utility steam for operating a motor and generator combination of dynamo through a heat exchange network such that sufficient electricity will be produced from the radiant energy received for application to the electrodes of the electrolysis cell abovementioned.

Accordingly, a principal object of the present invention is to provide a new and improved radiant-energy responsive power and/or product system including hydrogen generation and usage.

A further object of the invention is to provide an electrical power system incorporating a shunt sub-system incorporating hydrogen generation, supply, and ignition so that supplemental electrical power can be generated and supplement the primary system as needed.

A further object is to provide a radiant-energy actuated hydrogen generation and supply system, permissibly utilizing a heat engine, which is designed for continuous or semi-continuous usage, and storage, in a variety of industries and for a variety of uses.

A further object is to provide a closed electrolysis system wherein the exhaust products of a hydrogen engine associated therewith are returned to replenish the water supply of the electrolysis cell thereof.

A further object is to provide a regulated or uniform power system which is supplied by intermittent power.

A further object is to provide a hydrogen generation and storage system responsive to incoming radiant energy and provided with valve means such that hydrogen output in the system is maintained by requisite hydrogen storage.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawings in which:

FIG. 1 is a schematic of the basic system of the present invention in a preferred embodiment thereof and illustrating a number of uses.

FIG. 2 illustrates that a solar cell array may be employed of the radiant-energy to electrical-energy converter stage of FIG. 1.

FIG. 3 illustrates that the aforementioned converter may be a two-step system incorporating a radiant-energy to mechanical-energy converter substage coupled to a mechanical-energy to electrical-energy converter substage.

FIG. 4 is a schematic drawing illustrating the manner in which hot water and/or steam from a utility, from a geothermal cell or other means can be employed to drive a motor-generator unit for producing the electricity necessary for the electrolysis cell of FIG. 1, to thereby generate large hydrogen storage for subsequent use as a fuel, for continuous electrical generation, or for other uses.

FIGS. 5A and 5B are schematic drawings of a representative heat engine of the Stirling type.

FIG. 5C is a diagrammatic presentation of another type of heat engine that can be employed for producing mechanical power as per the first stage of FIG. 3.

FIGS. 6, 7 and 8 are schematic diagrams principally in block form of fluid-included receptacles which are heated by the sun's rays for producing mechanical power and, ultimately, electrical power, and this whether by steam engine as in FIG. 6, by steam turbine as in FIG. 7, or by a gas system including a gas turbine as in FIG. 8.

It is to be noted that recent developments in numerous arts which are related in the present invention make the combinations set forth both possible and practical.

In FIG. 1 a radiant-energy to electrical-energy converter 10 may take any one of several forms as will be hereinafter explained. In a system to be described, a



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highly unusual and efficient form of converter 10 will be a solar cell array 11 as seen in FIG. 2.

As to the solar cells, solar cell modules and arrays that may be utilized in the present invention at 10 and 11, the same are manufactured by many sources including the silicon solar cell modules known as HFSP-2-40, manufactured by the Centrelab Semiconductor Division of Globe Union Incorporated. Substantial reduction in the cost of silicon solar cells is at present very promising in the developments made by Tyco Laboratories, current efforts of which company are in the production of silicon ribbon. This is an edge-defined, film-fed growth (EFG) process which permits the growth of crystals in a shape desired, i.e., ribbons which can be readily converted into silicon wafers. Such developments promise to reduce the cost of silicon solar cells by a factor of from 10-25.

Converter 10 will supply primary electrical power via lead 12 and also auxiliary electrical power at leads 13 and 14 which are coupled to electrodes 15 and 16 of electrolysis cell 17. Electrolysis cell 17 may take any one of several forms and in the usual configuration will include a perforate baffle 18 disposed between the electrodes 15 and 16.

As to the electrolysis cells that can be utilized at 17 in FIG. 1, the most effective cells utilize an electrolyte of approximately 34% by weight of potassium hydroxide or 25% by weight of sodium hydroxide, this when the cell is operated at about 170° F. This heat can be supplied simply by the heat liberated during the electrolysis operation, so that such is sufficient to maintain the cell at a desired operating temperature. Two types of cells are employed and both are usable in the invention herein. These types are called the unipolar or tank-type cell, and also the bipolar or filter-press type. Diaphragms used as at partition 18 in FIG. 1 prevent the mixing of hydrogen and oxygen and are generally of asbestos cloth, wire screen, or perforated nickel plate. Typical examples of unipolar cells are the Knowles, Fausar and Burdett electrolytic cells. Closed tank unipolar cells include the International Oxygen Company and Consolidated Mining & Smelting Company tube cells, by way of example. The cells above described operate at 100% current efficiency, but on the basis of energy consumption and work produced are about 70-80% efficient. Note, however, that on the basis of hydrogen and oxygen and per ampere hour delivered, these cells are practically 100% efficient.

Cell 17 can be open rather than closed, and hence may comprise an ocean, a lake, pond, or watercourse, and especially those of brackish waters or simply containing salts. Further, the water supplied "cell" 17 may be reconstituted water absorbed from the atmosphere by a silica gel or dessicant, evaporated and distilled therefrom.

Electrolysis cell 17 will include a water inlet port 19 to which inlet conduit 20, leading from water reservoir 21, is connected. Electrolysis cell ports 22 and 23 are respectively coupled by conduits 24 and 25 to compressors 26 and 27. Compressors 26 and 27 are each respectively coupled by conduits 28 and 29 to oxygen storage device 30 and hydrogen storage device 31, respectively.

Turning first to the hydrogen storage device 31, it is seen that conduit 32 leads therefrom through manually or otherwise actuatable valve 33, coupling therefrom to conduit 34 that serves as a hydrogen intake for hydrogen engine 35. It is important that device 31 supply a constant volume of gas per unit time even though hy-

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drogen generation at cell 17 be intermittent. This can be accomplished, where device 31 is simply a pressure tank or cylinder, by using at 33 a self-regulated flow valve, such as a Racine flow valve, or by utilizing thereat a throttling-type regulator such as throttle regulators manufactured by the Maxitrol Company of Detroit, Michigan. Alternatively, device 31 may comprise a pair of series-coupled storage tanks, with a compressor interposed therebetween and responsive to final tank internal pressure for maintaining a constant pressure threshold. Whatever structure is used, it is important that hydrogen outflow proximate tee 112 be essentially constant, even if hydrogen generation at cell 17 might be intermittent due to ambient conditions. All compressors herein can be supplied independent power sources, solar-powered or otherwise, or simply be coupled to generator 42 or leads 12, 14, for example.

Oxygen storage tank 30 may be provided with outlet conduit 36 and valve 37 for simply producing an oxygen supply for any one of several purposes but which also may be coupled by conduit 38 as an oxygen intake, in lieu of air, to hydrogen engine 35. Of course, oxygen may likewise be supplied by the ambient atmosphere or by other means as is shown by oxygen inlet 39. The combustion product, namely, water, is drained from the engine 35, is cooled, and is routed back to the reservoir 21 in a closed, water-replenishing system. Hydrogen engine 35 includes an output shaft 41 which is coupled to electrical generator 42. Engine-generator, motor-generator, and dynamo are to be understood to be interchangeable and equivalent. The output of electrical generator 42 may be coupled back to the electrical power circuit at 12 via switch 43 and leads 44 and 45 coupled thereto, as desired.

Rather than employing a solar cell array for example, as the converter 10, the converter may be itself formed of two stages such as a radiant-energy to mechanical-energy converter section 46 and a mechanical-energy to electrical-energy converter section or stage 47, both forming a converter 10A corresponding to converter 10 in FIG. 1. See FIG. 3 in this regard. The mechanical-energy to electrical-energy converter would take the form of the general direct current generator shown, for example, in FIGS. 4 and 6-8. The radiant-energy to mechanical-energy converter may take any one of several forms as is illustrated in FIGS. 4-7.

In returning to FIG. 1, it is seen that a tee 101 may be provided in conduit 25 to provide for the connection thereto of conduits 102 and 103 with three-way valve 104, used alternatively for charging container 105 and then for conducting hydrogen therefrom at desired times. This combination is connected to a metal hydride-containing container 105. By metal hydride is meant any metal which has the capacity to absorb hydrogen gas. A number of metals, metal alloys and mixtures are available. Palladium metal is one possible substance that will hold 800 volumes of hydrogen at room temperature and atmospheric pressure. The weight absorbed will increase with the pressure at which the system is operated. Metallic uranium will also absorb considerable quantities of hydrogen at room temperature and release it when elevated in temperature. Where a heat source is needed, the same may be supplied proximate the container 105 as at heat source 106 in FIG. 1. Line 103 is connected to conduit 34 via tee 105', supplied as needed. Line 103 may likewise be provided with a tee connection at 106' where the hydrogen received from the metal hydride within container 105 is

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delivered to a hydrogen utilizing equipment or unit at 107.

FIG. 1 also illustrates that a tee connection 108 leading to H-O fuel cell 109 may be provided for generating electricity at 110. Fuel cells of current design and operating on hydrogen as delivered by tee 108 may be from 40-70% efficient. The oxygen needed by the fuel cell can be supplied directly from line 24, as indicated by branch line 111 or may be simply supplied by the air.

A tee 112 may likewise be used with a conduit 113 coupling to a synthetic ammonia plant 114. These plants here will operate by use of distilled atmospheric nitrogen for example and compressed hydrogen as delivered by valve 33 and hydrogen storage device 31 but without the usual steam and fossil fuel or petroleum feedstocks otherwise necessary to produce the hydrogen required. There are many types of synthetic ammonia plants in existence utilizable at 114 and using many types of processes, known as, for example, the Haber process, the Haber-Bosch process, the Fauser process, the so-called NEC process, and so forth; plants utilizing one or more of these processes have been built by many companies including the Kellogg Company, Nitrogen Engineering Corporation, also known as the Nitrogen Research Laboratory of the United States. Thus, both hydrogen and electric power may be supplied the ammonia plant 114 via electrical power lead 115 and the hydrogen proceeding by conduit 113 to the plant.

It is most important to note that ammonia, which is an important constituent of nitrogen fertilizer, is herein very inexpensively produced, this simply through the use of water, air, and radiant energy such as heat or the sun's rays, for producing by electrolysis both power and hydrogen to operate the plant.

By virtue of the solar-powered systems, for example, of the subject invention, hydrogen is generated extremely inexpensively. Herefore, use of hydrogen as a fuel has been extremely limited to certain special industrial purposes, this because of the great cost of producing hydrogen. In the past, the methods of producing commercially hydrogen favor the catalytic oxidation of carbon monoxide in blue-water gas. Low temperature fractionation of coal gas has also been used. These are expensive processes and require the presence of valuable hydrocarbons and fossil fuels. The present invention, in contrast, simply provides a usable fuel, namely hydrogen or ammonia, by the presence merely of water, air, and solar power, for example.

In FIG. 4, hot water and/or steam from a geothermal plant or from an electrical generating facility such as a nuclear power plant or hydrocarbon fuel type power plant as at 48 provides a hot water or steam residual output which is coupled by conduit 49 to input port 50 of heat exchanger 51. The super-heated water or steam passes through the heat exchanger and out exhaust port 52. Ports 53 and 54 are coupled by conduits 55 and 56 as indicated to a heat engine 57. The latter may comprise a steam engine, a vapor or gas engine, an ammonium engine, and so forth, at 57. In any event, there will be, for engine 57, a mechanical output shaft at 57' that can run generator 59 to produce electrical energy at 60 and 61. Accordingly, in FIG. 4 the energy from the hot water or steam of the electrical generating facility such as a public utility electrical power plant, for example, is utilized as to its super-heated water or steam to run a small stand-by, auxiliary, or shunt facility that can produce an additional electrical current suitable for coupling to the electrolysis cell 17 of FIG. 1.

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The hydrogen produced in FIG. 1 is stored at 31 and then fuels at desired times engine 35 for supplying additional electrical energy at 44. Such a facility, excess electricity or power during off peak-load periods can be employed to generate hydrogen and, subsequently, additional electrical power to satisfy peak load added requirements, thereby reducing utility size and costs.

FIGS. 5A and 5B illustrate an optional type of radiant-energy to mechanical-energy converter in FIG. 3 as by what is known as a Stirling hot-air engine. See Stirling engine 62 in FIGS. 5A and 5B. The conventional Stirling engine is shown in diagrammatic form and includes cylinders 63 and 64 with pistons 65 and 66. Coupled to each piston by a pivot pin 67 and 68 is a swinging piston rod 69 and 70, respectively. Each of these piston rods are pinned at 71 and 72 to conventional flywheel 73. Cylinders 63 and 64 are intercoupled by conduit 74 of relatively small size which includes a heat-trapping steel-wool type gauze at 62'. The gauze is air pervious and yet tends to keep the heat entrapped within cylinder 63. Hot-air engines of the type shown in FIGS. 5A and 5B are quite efficient, noiseless and show considerable promise. The principle of operation is that the sun's rays at 75 are focused by a reflector or focus through a lens 76 to a translucent or transparent plastic window 77 to heat the air or other fluid 78 within cylinder 63 above piston 65. The rapidly expanding air urges piston 65 downwardly and, by virtue of the flywheel 73, piston 66 upwardly. As the flywheel continues to turn it moves the second piston 66 downwardly and piston 65 upwardly, thereby forcing the hot air in a direction to the right through conduit 74 into cylinder 64 above piston 66. At this point the heat is exhausted in cylinder 64 and the sun's rays at 75 will operate to reheat again the volumetric air in cylinder 63 above piston 65. Steel wool gauze 62' is used to preheat the now-cooled air in cylinder 64 which returns to cylinder 63. The preheated air is expanded further as aforesaid by the light from the sun that heats the air above piston 65. It is noted that this is a thermal heat engine machine of a closed-system type.

In FIG. 5C a closed container 116 is employed which includes a transparent or translucent top 117 and also an inner side and bottom "black" layer 118. The tank 116 is filled, through the side valve shown, with one of the so-called true gasses or simply with an easily vaporized liquid such as ammonia dissolved in water.

The upper surface 117 is exposed to sunlight, heat, or other radiant energy source so as to vaporize or expand the working fluid 119 within the interior of container 116. The vapor or gas rises in conduit combination 126 to proceed to turbine 121. Jacket means 122 is disposed about hollow cylindrical structure 123 beneath the turbine, the latter being connected by conduit 124 back to container 116. The means 122, of increased volume, is used to cool the structure 123 and the working fluid used passing therethrough in the direction shown by the arrow by virtue of gas expansion in 122. Hence, this cooling may be ideally performed by the insertion of condenser or cooling unit 122 into hydrogen line 25, see FIG. 1, and shown here as line portions 25A and 25B. The portion 25B will again be connected directly to compressor 27, hydrogen thus serving as said working fluid.

In operation in FIG. 5C, the true gas is heated and expands or vapor such as ammonia from an ammonia water solution is vaporized upwardly such that the gaseous or vapor stream enters and moves turbine 121.

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This vapor is cooled at structure 123 since there exits a heat exchange communication with the interior of structure 122. It is noted that structure 122 is an enlarged cavity leading to compressor 27. Accordingly, the hydrogen generated at the electrolysis cell 17 is utilized and expanded proximate structure 123 so as to cool this area and thereby supply a pressure gradient or differential as between the vapor pressure at X and the pressure at Y. This provides a turning of the turbine 121 so that the turbine may be used to supply mechanical, or electrical power at generator G in FIG. 5C via the revolving coupler shaft 125 which generator G may indeed comprise the mechanical-energy to electrical-energy converter 47 in FIG. 3. The shaft 125 may be adapted for manual revolvment until the system gets up to a speed sufficient to release the necessary hydrogen to cool the lower structure 123 and thereby supply the gaseous pressure gradient upon which revolving turbine 121 will rely.

FIG. 5C illustrates therefore, another form of prime mover for supplying energy such that the same may be coupled to electrodes 15 and 16 by virtue of leads 14 and 15 and the switch S' used.

Other means of producing mechanical power to supply electrical energy for electrodes 15, 16 of the cell 17 in FIG. 1 from radiation is shown in FIG. 6. Thus, a very large shallow vessel at 79 is supplied a black coating at 80 and is filled with water or other liquid or fluid at 81. A series of reflectors 84A, 85A, 84, and 85, are used to concentrate the sun's rays in a particular area. For convenience of illustration, the vessel has been expanded in a horizontal direction relative to the reflectors. Thus, the shallow pool may be many times smaller in dimension than the distance between the reflectors 84A and 85A. In any event, the sun's rays are concentrated on the darkened or black surface 80 to produce a low pressure steam within the vessel and beneath the transparent or translucent top 82 thereof. The steam is conducted by conduit 83 to a steam engine S' which produces mechanical output power at shaft S''. Shaft S'' may be coupled to electrical generator G' such that the latter may generate a DC current.

The structure in FIG. 7 is slightly different, this time including a steam turbine 86. Vessel 87 has a translucent top as of glass or plastic at 88 and includes on the sides and bottom thereof at 89 dark black coating 90. Disposed within the vessel in FIG. 7 is a water which is preferably brine laden such that the temperature of the water will rise appreciably and will remain hot for a substantial period of time. The steam generated, of from one to two atmospheres, is piped through conduit 91 into a conventional low-pressure operated steam turbine 86 for producing mechanical power at shaft 92 of the turbine. This shaft again powers DC generator 93. Alternatively, a hairpin configured conduit 91' can be immersed in the brine to supply circulating vapor pressure to turbine 86.

In FIG. 8 there is likewise a vessel at 94 having a translucent or transparent top surface made of glass or plastic as at 95. A darkened, painted or pitch surface 96 is provided. The vessel in FIG. 8 may be filled with any type of fluid, gas or liquid which is heated to a gaseous state by the sun's rays to revolve gas turbine. Thus, the vessel at 94 includes the fluid and the vessel was cou-

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pled by conduits 97 and 98 to gas turbine 99 of a low-pressure, low-temperature type. Accordingly, the sun's rays radiate downwardly upon translucent or transparent face 95 to heat the fluid disposed within the tank, and such gas is used to revolve the turbine 99 which, in turn, is coupled to and drives generator 100.

The terms "power" and "energy" as used herein shall be considered synonymous which shall include both electricity and heat, by way of example. Thus, unit 35 in FIG. 1 may comprise simply a furnace using oxidized hydrogen fuel which can be employed to serve as a supplementary heat source for heating or cooling solar heated homes and other buildings. The invention is usable in every context wherein hydrogen, or electricity, or heat produced therefrom, are to be employed as a continuous "power" source which will serve as a standby or auxiliary unit to supplement primary sources.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. An electrical power system including, in combination: first structural means directly responsive to impingement thereon of the sun's rays for converting the sun's radiant energy in said rays as so received into electrical energy, said first means including a pair of opposite-polarity, electrolysis, electrical connectors; second electrolysis means having water incorporating a salt-type electrolyte for generating hydrogen at a lower pressure and also oxygen, said second means having a pair of separated electrodes respectively coupled to said electrical connectors, a water inlet, and hydrogen and oxygen gas outlet ports respectively disposed cooperably with said electrodes; third means coupled to said hydrogen port and utilizing the hydrogen therefrom for producing a useful result; hydrogen storage means, including an electrically operated compressor, interposed between said second and third means, for storing hydrogen at a higher pressure, said hydrogen storage means being provided with means for regulating hydrogen flow from said hydrogen storage means to said third means for essentially uniform flow.

2. The combination of claim 1 wherein said first structural means comprises a solar cell array.

3. The combination of claim 1 wherein said first structural means comprises solar-heating-vessel for generating steam and a turbine-generator coupled thereto.

4. The combination of claim 1 wherein said first structural means comprises a solar heat engine, and electricity-generating means coupled thereto.

5. The combination of claim 1 wherein said third means has a water exhaust and includes water-flow conduit means coupled to said second electrolysis means whereby to route said water-exhaust from said third means back to said second electrolysis means to replenish the water supply thereof.

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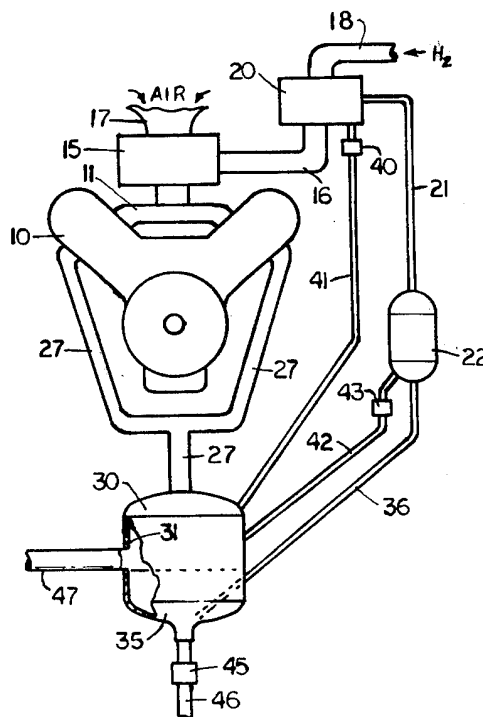
**United States Patent** [19][11] **4,167,919****Woolley et al.**[45] **Sep. 18, 1979****[54] METHOD AND APPARATUS FOR HYDROGEN FUELED INTERNAL COMBUSTION ENGINES****[75] Inventors: Ronald L. Woolley; Vaughn R. Anderson, both of Orem, Utah****[73] Assignee: Billings Energy Corporation****[21] Appl. No.: 855,302****[22] Filed: Nov. 28, 1977****[51] Int. Cl.<sup>2</sup> ..... F02D 19/00; F02D 47/00****[52] U.S. Cl. .... 123/1 A; 123/25 R; 123/25 E; 123/DIG. 12****[58] Field of Search ..... 123/1 A, DIG. 12, 25 R, 123/25 E, 3****[56] References Cited****U.S. PATENT DOCUMENTS**

2,671,311	3/1954	Rohrbach .....	123/25 R
3,362,883	1/1968	Wright .....	123/DIG. 12
3,696,795	10/1972	Smith et al. ....	123/DIG. 12
3,817,221	6/1974	Nohira et al. ....	123/25 R
3,818,875	6/1974	Phillips et al. ....	123/1 A
3,842,808	10/1974	Cataldo .....	123/25 R

3,983,882 10/1976 Billings ..... 123/DIG. 12  
 4,003,343 1/1977 Lee ..... 123/DIG. 12

*Primary Examiner—Ira S. Lazarus**Attorney, Agent, or Firm—Criddle, Thorpe & Western***[57]****ABSTRACT**

An internal combustion engine designed to operate with hydrogen fuel, comprises means for mixing water in the form of droplets, spray, or mist with gaseous hydrogen. The water-containing hydrogen gas is then introduced along with air in proportion for practical internal combustion and efficient power output to the cylinders or combustion chambers of the engine for combustion. In one embodiment of the invention, water vapor is condensed from the exhaust gases from the engine, and the condensed water is used as the source of water to be mixed with hydrogen fuel so as to provide a continuing, self-supporting system. The resulting exhaust emissions from the engine are very low in oxides of nitrogen, and, in addition, engine backfiring is eliminated while the efficiency and power output of the engine is improved.

**16 Claims, 4 Drawing Figures**

## U.S. Patent

**Sep. 18, 1979**

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FIG. 1

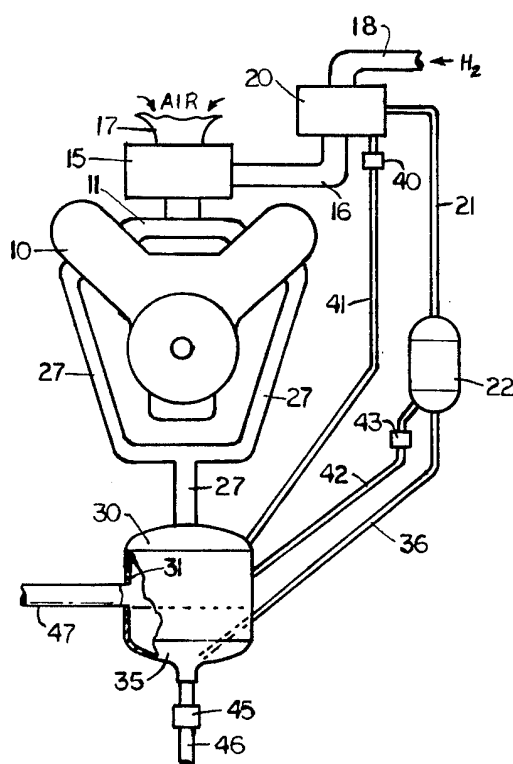


FIG. 2

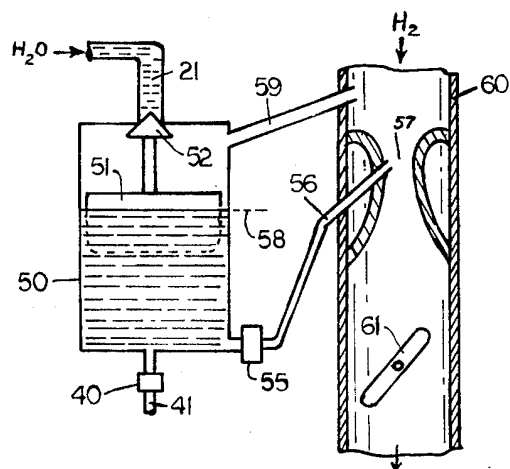


FIG. 4

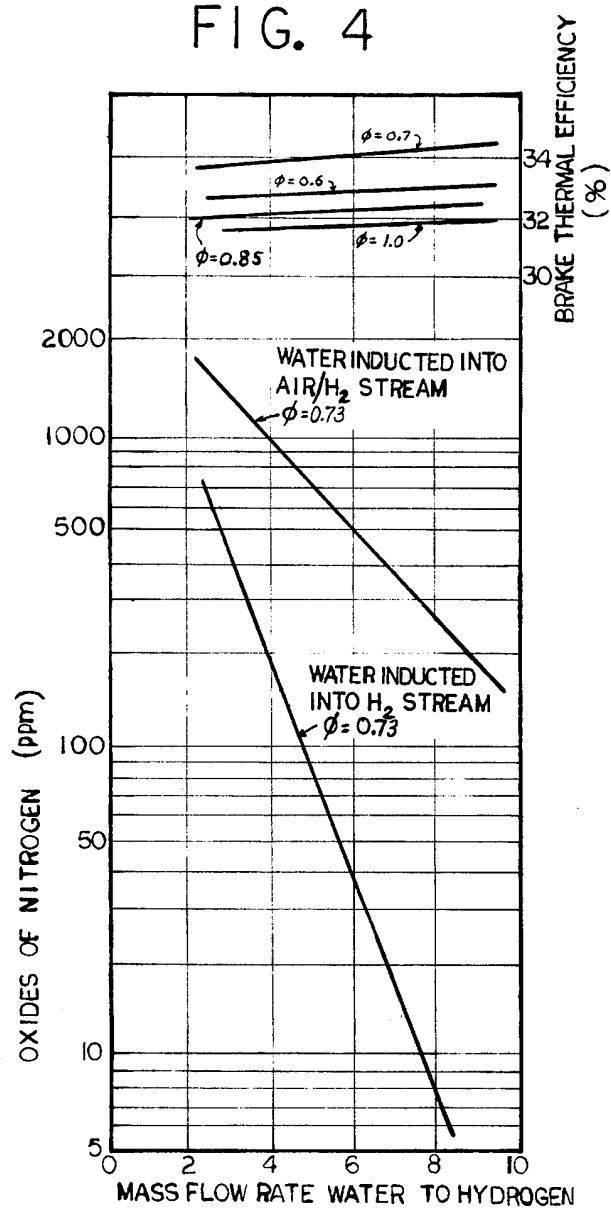
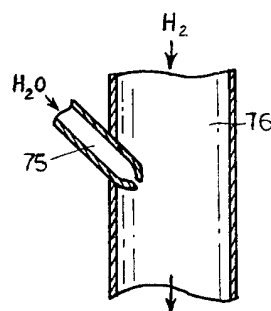


FIG. 3



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## METHOD AND APPARATUS FOR HYDROGEN FUELED INTERNAL COMBUSTION ENGINES

### BACKGROUND OF THE INVENTION

Field: This invention relates to internal combustion engines which are designed to operate on gaseous hydrogen fuel. In particular, the invention relates to methods of inhibiting backfiring and reducing the generation of oxides of nitrogen during the operation of such engines.

State of the Art: Internal combustion engines utilizing hydrogen fuel may be operated at low power outputs without difficulty provided the timing is properly set for the gaseous hydrogen mixture used as the fuel. At higher power outputs, an intermittent problem of ignition in the intake manifold (backfiring) is encountered. Without some means of suppression of backfiring, the engine cannot be made to run continuously at the higher power outputs required in conventional automobiles. In addition, the formation of oxides of nitrogen ( $\text{NO}_x$ ) increases as the power output of an internal combustion engine operating on hydrogen fuel is increased.

In U.S. Pat. No. 3,983,882, issued to Roger E. Billings on Oct. 5, 1976, it is reported that the addition of water to the hydrogen-air mixture in the intake manifold of an internal combustion engine is an effective means of suppressing the tendency of the engine to backfire and of reducing the production of oxides of nitrogen during the combustion. In accordance with the teachings of that patent, gaseous hydrogen fuel is mixed with a predetermined amount of air, and water is added to the mixture of hydrogen and air at the intake manifold of the engine.

### SUMMARY OF THE INVENTION

In accordance with the present invention, water is inducted into the hydrogen fuel stream, and the water-laden hydrogen is mixed with air and delivered to the engine intake for sequential combustion in the cylinders of the engine. Conventional internal combustion engine structures and tooling are used. Although water from any source could be used in accordance with the invention, in a preferred embodiment of the invention, water vapor formed during the combustion of hydrogen is condensed and used as the source of water inducted into the hydrogen fuel stream. A reservoir maintains a water level ample for the induction operation. Sufficient water is produced to maintain predetermined water input. The formation of oxides of nitrogen in the combustion process of the hydrogen fuel is reduced by a factor of between 3 and 20 in comparison with the hydrogen internal combustion engine systems of U.S. Pat. No. 3,983,882, by introducing the water directly to the hydrogen fuel stream prior to admixing the hydrogen fuel with air. Backfiring to the intake manifold of the engine is eliminated as a problem in the hydrogen fueled engine of this invention. The input water quenches the hydrogen combustion process, thereby slowing down the hydrogen combustion rate, and thus substantially eliminating the backfiring problem.

Water is introduced into the hydrogen fuel stream by an injector nozzle or carburetor. The water-laden hydrogen is then mixed with air in a conventional gas metering device. The hydrogen-air mixture is then fed to the intake of the internal combustion engine.

A static water storage tank is not needed but could be employed if desired. Thermostatically controlled drains

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automatically empty water-using components to prevent their freezing-up when the engine is out of use during freezing conditions. Anti-freeze is not required. Sufficient water becomes available promptly upon start-up of the engine, and thus replenishment or storage is unnecessary.

### THE DRAWINGS

FIG. 1 is a diagrammatic representation of an exemplary form of the hydrogen fueled engine system in accordance with the present invention.

FIG. 2 is a schematic cross-sectional view of a carburetor used in introducing water in predetermined mass ratio with the hydrogen fuel stream.

FIG. 3 is a schematic cross-sectional of an injector nozzle used to introduce water into the hydrogen gas stream.

FIG. 4 is a graph showing the reduction of oxides of nitrogen achieved by the present invention and the relationship between engine efficiency and the equivalence ratio of hydrogen to oxygen in the fuel being burned.

### DESCRIPTION OF THE INVENTION

The engine 10 of FIG. 1 utilizes two carburetors 15 and 20 in series flow relation. Carburetor 15 is designed to mix hydrogen gas and air, and feed the gas mixture to the intake manifold 11 of the engine 10. Gaseous hydrogen ( $\text{H}_2$ ) is fed to carburetor 15 via supply line 16. Line 16 is supplied with gaseous  $\text{H}_2$  at relatively low pressure. Air input duct 17 leads into the carburetor 15, and air is mixed in preset proportion with the gaseous hydrogen being introduced through line 16. A commercially available carburetor for unit 15 is an air-gas valve diaphragm-operated type, as made by IMPCO.

The gaseous hydrogen fed to carburetor 15 contains water in the form of vapor, droplets, mist, spray, or combination thereof. Water is introduced into the hydrogen stream in supply line 16 by carburetor 20 which is located upstream of line 16 from carburetor 15. Carburetor 20 may be the usual liquid-gas type, and serves as the water metering device. Gaseous hydrogen at relatively low pressure is introduced into carburetor 20 through duct 18, and water is introduced into carburetor 20 by supply line 21. The carburetor 20 is readily adapted for the hydrogen and water flow respectively, by making its jet nozzles of suitable size, or by adjusting its metering capability of hydrogen and water, respectively.

Condensed water is directed in the carburetor 20 through supply line 21 by pump 22. The predetermined mass ratio of water to hydrogen in the gas mixture from carburetor 20 is substantially maintained by the settings in that carburetor. The overall air proportion with respect to both hydrogen and water is maintained by the settings in carburetor 15, as will be understood by those skilled in the art.

The mixture of air, hydrogen, and water is conducted, in a quantity or volume as determined by the throttle setting of carburetor 15, into the intake manifold 11 of engine 10 for sequential combustion in the cylinders thereof. The exhaust from engine 10 is introduced directly to condenser 30 by exhaust manifold 27. The condenser 30 serves as a pre-cooler, and acts to muffle sounds from the engine 10. The interior surface of the walls 31 of condenser 30 are proportioned to condense out and convert contained water vapor into

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sufficient water for the peak demands of the engine 10. The water enters a small reservoir section 35 of condenser 30, wherein it is retained for future induction to carburetor 20. A feed line 36 extends from an opening in the lower region of the reservoir 35 to the input of water pump 22. Water pump 22 then forwards the water through supply line 21 to carburetor 20. Pump 22 may be electrically driven or mechanically driven from the engine.

The condenser 30 is designed to condense out water 10 at a sufficient rate to serve under all steady-state driving conditions. A small reservoir section 35 is included in condenser 30 to store enough water to handle at least the rapid transient drive demand, such as the passing of another car at high speed. A storage of from about  $\frac{1}{2}$  to about 2 or 3 liters of water is sufficient for such spurts, depending on the power output of the engine. Residual gases and water vapor from the exhaust within condenser 30, together with excess condensed water or overflow from reservoir 35 exit through the exhaust 20 pipe 47.

An important feature in the present invention, is a system to automatically prevent water freeze-up in the components of the water induction sub-system during freezing conditions when the engine is not in use. Towards this end, a thermostatically controlled valve is placed at the drain port of water carburetor 20, at the chamber drain of pump 22, and at the base of the reservoir 35. Thermal valve 40 at the base of carburetor 20 communicates to condenser 30 via tubing 41. Thermal valve 43 at pump 22 also is drained into condenser 30 by tubing 42. Thermostatically controlled valve 45 drains the reservoir 35 through exit piping 46. The thermostatic controls 40, 43, and 45 are preset to actuate their respective valves to "open" to effect their drain function at and below a predetermined temperature period. The preset temperature depends upon respective location in the engine compartment, and a somewhat empirical determination of what ambient temperature would result in freezing of the water within the engine compartment. Settings in the range of 32° F. to even 40° F. are in order with a "safe" setting being about 35° F.

In any event, when the engine is in operation, the engine compartment temperature is much above the preset temperature, and the valves remain "closed" even during sub-freezing winter weather, so that the water condensation and induction process can proceed. During engine start-up with the water drained, the engine warms up rapidly and triggers the temperature set valves to "closed". Further, condensation of sufficient water from the engine exhaust for induction to the engine with the hydrogen fuel is rapid. In fact the reservoir 35 fills with water quickly after start-up of the engine.

An exemplary water carburetor 20 is illustrated in FIG. 2. It is basically like a conventional gasoline carburetor. The water supply line 21 ends at a needle valve in the upper part of receiving chamber 50. When sufficient water is in chamber 50 the float 51 closes needle valve 52. A metering orifice or jet 55 is at the base of chamber 50. It proportions the flow of water into tube 56 that extends to the throat of venturi 57. The end of the tube 56 is above the water level 58. A vent line 59 extends from chamber 50 into mixing chamber 60. Throttle valve 61 is positioned in the exit region of chamber 60.

FIG. 3 shows another version of apparatus applicable for mixing water with the hydrogen gas stream. In this version jet nozzle 75 is used to inject water into the

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hydrogen stream in place of the carburetor described hereinbefore. The gaseous hydrogen is fed directly to the supply line 16 of carburetor 15, through the injector nozzle 75. Water is injected into line 16 in measured amount through nozzle 75 in known manner. The resultant water spray mixes with the hydrogen gas stream, and the gas mixture is passed to the intake manifold 11 of the internal combustion engine 10. The mass ratio of the water to hydrogen in the combined mixture (with air) is predetermined as set forth hereinafter for optimum results. The injector nozzle may be mechanical devices known in the art, as well as electronic injectors, such as manufactured by the Robert Bosch Company of Stuttgart, Germany.

The term "induction" is used to mean that mixing is accomplished by the fluid dynamics of the intake system, as by vacuum, venturi, orifices, and the like. The term "injection" is used to mean that the input is forced directly through an injector nozzle, as by a pump. "Introduction" is used herein as a generic term with respect to "induction" and "injection", or other manner of mixing water with gaseous hydrogen and presenting the hydrogen mixture to the intake of the engine.

The condenser 30 as shown in FIG. 1, may be an "open box" having its internal walls 31 serving as the condensing structure. Walls 31 are exposed internally to the hot vapor-laden exhaust. The exterior of the walls are exposed to the ambient temperature in the engine compartment region. For a small (50 brake horsepower) vehicle, about 2.5 square feet of internal wall 31 surface will continuously condense-out sufficient water for the engine system thereof. The surface required is generally linear with the brake horsepower of the engine. Thus, a 100 brake horsepower car would use about 5 square feet of internal wall surface 31 in condenser 30. A "collection chamber" is preferably included within unit 30, so that water droplets will precipitate from the exhaust stream rather than for the most part be blown out through the tailpipe 47. Condenser 30 configuration and size may be optimized by methods well known in the art, such as by corrugation of the walls, or by interior finned tubing as through which an engine cooling medium passes. A series of tests were performed on a V-8 engine which had been modified to raise the compression ratio from about 8:1 to about 12:1 for operation using gaseous hydrogen as the fuel. The modification was accomplished by replacing the pistons in the engine and shaving the heads slightly. The engine was mounted on an induction dynamometer manufactured by the General Electric Company. The ignition system of the engine was essentially the same as supplied by the manufacturer thereof.

Oxides of Nitrogen ( $\text{NO}_x$ ) were measured with a Thermoelectron, Series 14, Chemiluminescent Analyzer, Model 12A. This analyzer provided interference-free, linear, continuous monitoring of engine exhaust. Equivalence ratio, i.e., the fraction of hydrogen contained in the fuel mixture relative to the chemically correct quantity for a given amount of oxygen in the fuel mixture, was monitored by measuring the amount of oxygen remaining in the exhaust gas with a Beckman oxygen analyzer, Model 715.

In one set of tests, water was inducted into the air-hydrogen mixture in the intake manifold of the engine, in accordance with U.S. Pat. No. 3,983,882. In a second set of comparative tests, water was mixed with the hydrogen stream, and the water-laden hydrogen was then mixed with air, to produce a fuel mixture which

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was then delivered to the engine intake for sequential combustion in the cylinders of the engine. In both sets of tests, the water flow rate was measured by a Fisher-Porter rotameter, and the hydrogen flow rate was measured with a Schutle and Koerting rotameter, using the calibration curve supplied by the manufacturer.

The results of these tests, in general, confirmed the teaching of U.S. Pat. No. 3,983,882, in that the induction of water into the fuel, whether mixed with the hydrogen gas prior to or after mixing of the hydrogen gas with air, has positive advantages both on emissions and on performance of the engine. The generation of oxides of nitrogen is greatly reduced, and backfiring of the engine is eliminated when mass ratios of water to hydrogen of above two are used. However, as can be seen from the results shown in FIG. 4, a 3-fold to 20-fold reduction is achieved in the amount of oxides of nitrogen generated by the engine by the process of the present invention in comparison to the process of U.S. Pat. No. 3,983,882. In addition, another significant improvement is obtained by the present invention. As shown in FIG. 4, for any given equivalence ratio the percent oxides of nitrogen generated can be reduced greatly. This allows operation of the engine at its highest possible equivalence ratio, and as shown in the upper portion of FIG. 4, the break thermal efficiency of a hydrogen-fueled, internal combustion engine tends to be a maximum at an equivalence ratio of about 0.7. When the engine upon which the present tests were made was operated using the prior art method of inducting water and at an equivalence ratio of about 0.7, it generated at least 200 parts per million oxides of nitrogen in its exhaust. On the other hand, by inducting the water in accordance with the present invention, the same engine operates at the equivalence ratio of 0.7, with less than about 10 parts per million oxides of nitrogen generated in its exhaust.

Although applicants do not intend to be limited by any theory of operation of the invention, it is believed that by inducting the water into the hydrogen stream ahead of the air mixer, the water follows the hydrogen so that greater water concentrations are obtained where there is a greater fuel concentration. From studies of the exhaust from the individual cylinders of the engine, it has been shown that the distribution of hydrogen to the cylinders of the engine is slightly non-uniform, with about 10 percent variation occurring in the equivalence ratio between cylinders. The variance in equivalence ratio does not effect the overall performance of the engine; however, the production of oxides of nitrogen is an exponential function of equivalence ratio, and the slight nonuniformity can result in an order of magnitude difference in the production of oxides of nitrogen from cylinder to cylinder. By having greater concentration of water where there is a greater fuel concentration, the suppression of the formation of oxides of nitrogen is optimized.

We claim:

1. An internal combustion engine comprising one or more combustion chambers; an engine fuel intake for delivering a fuel mixture of gaseous hydrogen and air to said chambers for sequential combustion therein; fuel feed means for providing a gaseous fuel mixture of hydrogen and air in metered relation to the engine fuel intake; a hydrogen supply line for introducing gaseous hydrogen to said fuel feed means; water distributing means for producing water droplets, spray, or mist from supplied liquid water and for introducing said water

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droplets, spray, or mist to said hydrogen supply line to mix with the gaseous hydrogen therein prior to the introduction of said gaseous hydrogen to said fuel feed means; condensor means for condensing water vapor from the combustion gases resulting from the combustion of hydrogen in said chambers; and means for supplying the condensed water to said water distributing means in such proportion to provide sufficient water in the fuel mixture to inhibit backfiring during operation of the engine as well as to reduce the oxides of nitrogen in the exhaust gases from the engine.

2. An internal combustion engine in accordance with claim 1, wherein said fuel feed means is a carburetor that is adapted to mix the gaseous hydrogen and water mixture supplied thereto with intake air.

3. An internal combustion engine in accordance with claim 2, wherein said water distributing means is a second carburetor positioned in series flow ahead of the other carburetor, said second carburetor being adjustable to supply the intake water droplets, spray, or mist in a predetermined mass ratio proportioned to the intake hydrogen generally over the engine operating range.

4. An internal combustion engine in accordance with claim 3, wherein said second carburetor includes a metering device that in general maintains that mass ratio of the water to hydrogen in the gas being introduced to said first carburetor at a predetermined level.

5. An internal combustion engine in accordance with claim 4, wherein said metering device maintains that mass ratio of water to hydrogen in the order of 2:1 or greater.

6. An internal combustion engine in accordance with claim 3, wherein said first and second carburetor means are adjusted to maintain the mass ratio of the water to hydrogen supplied to the engine intake in the order of 2:1 or greater.

7. An internal combustion engine in accordance with claim 2, wherein said water distributing means is a device for injecting water droplets, spray, or mist to said hydrogen supplied line.

8. An internal combustion engine in accordance with claim 7, wherein said water distributing means injects water to said hydrogen supply line at a rate to maintain the mass ratio of water to hydrogen in the gas introduced to said fuel feed means in the order of 2:1 or greater.

9. In an internal combustion engine having an engine fuel intake, one or more chambers in which fuel combustion occurs, fuel feed means for introducing gaseous hydrogen and air in metered relation to the engine fuel intake for combustion in the chambers, and a hydrogen supply line for providing the fuel feed means with gaseous hydrogen, the improvement comprising: water induction means for producing finely divided water including droplets, spray, or mist from input water and for introducing the finely divided water into the hydrogen gas supply line; a reservoir for holding water; and means for conveying water from said reservoir to said water induction means, said water being added to the hydrogen in said hydrogen gas supply lines in such proportion as to inhibit backfiring and generation of nitrogen oxides when the hydrogen gas is subsequently combusted in said chambers.

10. An internal combustion engine in accordance with claim 9, wherein said water induction means comprises a carburetor which is adapted to mix finely divided water from input water with the hydrogen gas in said hydrogen supply line.



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11. An internal combustion engine as in claim 10 wherein said carburetor is adapted to maintain the mass ratio of the water to hydrogen in the order of 2:1 or greater.

12. An internal combustion engine in accordance with claim 9, wherein said water induction means comprises a device for injecting finely divided water into the hydrogen supply line.

13. An internal combustion engine in accordance with claim 12, wherein said device is adapted to maintain the mass ratio of the water to hydrogen in the order of 2:1 or greater.

14. A method of inhibiting backfiring and generation of oxides of nitrogen in a hydrogen-fueled internal combustion engine comprising: (a) storing water; (b) producing liquid water droplets, spray, or mist from the stored water; (c) mixing the droplets, spray, or mist

with gaseous hydrogen; and (d) introducing air and the gaseous mixture of hydrogen and water droplets, spray, or mist in metering relation to the engine intake for combustion in the cylinders, wherein the water droplets, spray, or mist is admixed with the hydrogen in a predetermined mass ratio sufficient to inhibit backfiring and the generation of oxides of nitrogen during the operation of said engine.

15. A method in accordance with claim 14 wherein step (a) comprises: (f) condensing water vapor contained in the exhaust from the hydrogen combustion process, and (g) depositing the condensed water in a storage reservoir.

16. A method in accordance with claim 14 wherein water is admixed with hydrogen in a mass ratio of water to hydrogen in the order of 2:1 or greater.

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**United States Patent** [19][11] **4,178,882****Anderson et al.**[45] **Dec. 18, 1979****[54] HYDROGEN FUEL SUPPLY SYSTEM**

[75] Inventors: **Vaughn R. Anderson; Ronald L. Woolley; Edward H. Davis**, all of Orem, Utah

[73] Assignee: **Billings Energy Corporation**, Provo, Utah

[21] Appl. No.: **871,094**

[22] Filed: **Jan. 20, 1978**

[51] Int. Cl.<sup>2</sup> ..... **F02B 43/10**

[52] U.S. Cl. .... **123/1 A; 123/3; 123/DIG. 12**

[58] Field of Search ..... **123/DIG. 12, 1 A, 3, 123/119 E, 136; 137/119**

**[56] References Cited****U.S. PATENT DOCUMENTS**

2,226,810	12/1940	Ensign et al.	137/119
3,834,359	9/1974	Ando	123/1 A
4,016,836	4/1977	MacKay et al.	123/3

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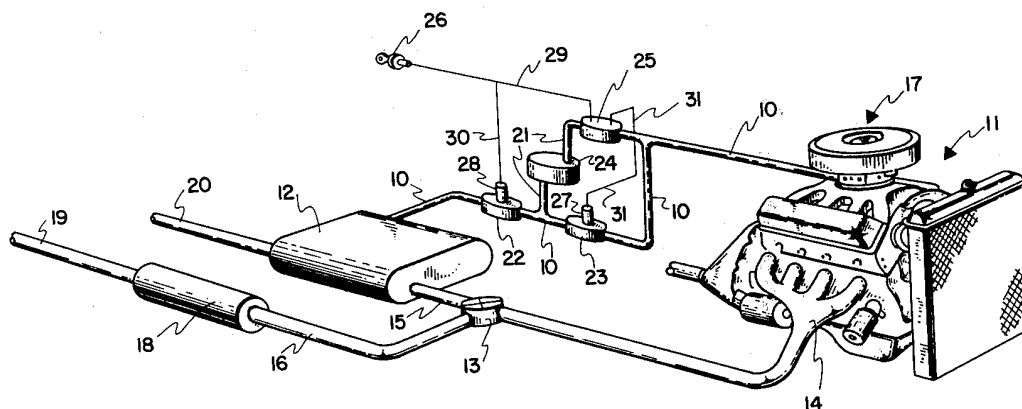
*Attorney, Agent, or Firm*—Criddle, Thorpe & Western

**[57] ABSTRACT**

A fuel supply system is provided for engines which are adapted to operate on gaseous hydrogen fuel and which utilize a fuel tank containing a metal hydride for the storage of hydrogen. The system provides for high pressure operation when the hydride in the fuel tank is fully charged with hydrogen, as well as for operation at

low pressures to allow maximum utilization of the hydrogen stored in the hydride. A supply conduit, which can supply the hydrogen needed during normal operation of the engine with minimal pressure drop, connects the storage tank to the fuel intake of the engine. A bypass conduit is provided having one end thereof connected to the supply conduit and its other end reconnected to the supply conduit downstream of the first connection. Valve means are adapted to direct the flow of hydrogen either directly through the supply conduit or to divert the flow of hydrogen from the supply conduit through the bypass conduit and back to the supply conduit downstream from the valve means. A pressure regulator is included in the bypass conduit which is capable of regulating downstream pressure at a preset pressure when the upstream pressure is greater than the preset pressure. A controller monitors the downstream pressure and when the monitored pressure falls sufficiently below the preset pressure of the regulator, the controller changes the valve means so that the hydrogen flows directly through the supply conduit. Thus, when the storage tank supplies high pressure hydrogen to the supply conduit, the hydrogen is routed through pressure regulating means in the bypass conduit, and when the pressure from the storage tank decreases below the regulated pressure, the hydrogen is routed through the supply conduit thereby avoiding substantial pressure drops as it flows from the storage tank to the engine.

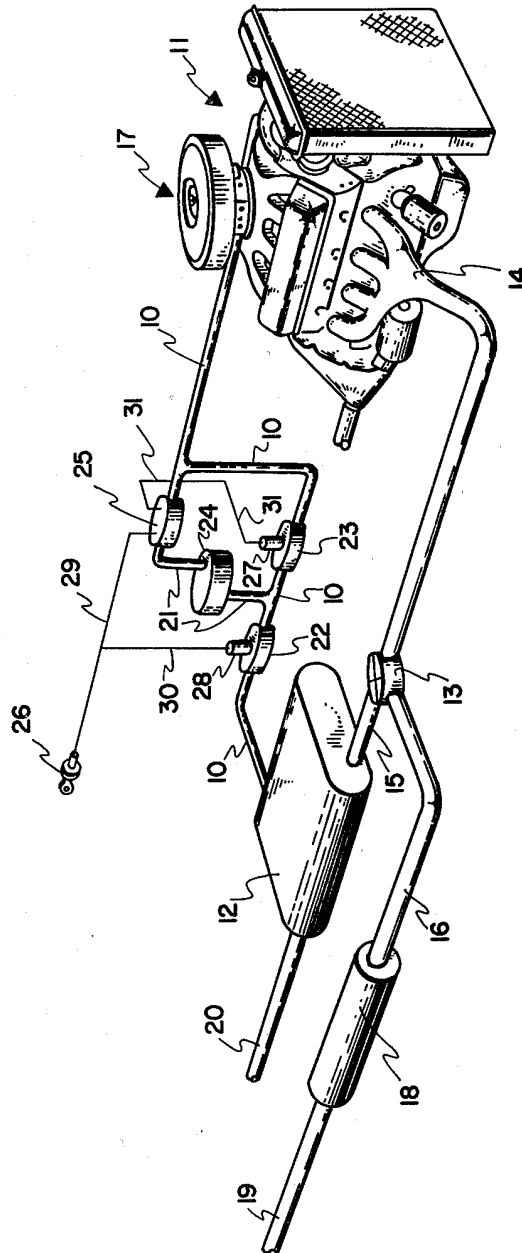
**8 Claims, 1 Drawing Figure**



U.S. Patent

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## HYDROGEN FUEL SUPPLY SYSTEM

### BACKGROUND OF THE INVENTION

#### 1. Field

The invention relates to internal combustion engines which are designed to operate on gaseous hydrogen fuel and which utilize a fuel tank containing a metal hydride for the storage of hydrogen. In particular, the invention relates to a fuel system for conveying the fuel from the storage tanks to the engine.

#### 2. State of the Art

Internal combustion engines utilizing hydrogen fuel have been shown to be both feasible and an attractive alternative to engines which utilize gasoline. See, for example, U.S. Pat. No. 3,983,882 issued on Oct. 5, 1976 to Roger E. Billings, as well as the references cited therein. The storage of hydrogen for use in internal combustion engines has presented difficult problems. However, the use of storage containers containing metal hydrides has mitigated many of those problems. See, for example, U.S. Pat. No. 4,016,836 issued on Apr. 12, 1977 to Donald B. MacKay et al.

The hydride-containing containers are typically charged with hydrogen at a pressure of about 500 psig or greater. This pressure must be regulated when the stored hydrogen is fed to the mixing device on the engine which mixes the hydrogen with air and introduces the mixture to the intake manifold of the engine. Regulators have been used in prior hydrogen fuel systems, wherein the regulator regulates the hydrogen pressure downstream therefrom at a preset pressure. As the hydrogen is used from the hydride-containing storage tanks, the pressure of the hydrogen released by the hydride is continuously reduced. At a point wherein the pressure of the hydrogen coming from the storage tanks is less than the preset pressure at which the regulator is set, the regulator becomes ineffective, and the pressure downstream therefrom is the pressure of the hydrogen coming from the storage tanks less the pressure drop incurred in passing through the flow conduits and the pressure regulator. Because of the relatively large pressure drop incurred, the hydride-storage tanks required recharging when the pressure therein fell to about 100 to 150 psig. Considerable hydrogen is still contained in the storage tanks at that pressure but is unavailable because of the pressure drop incurred in delivering the hydrogen to the engine.

#### 3. Objective:

The principal objective of the present invention was to provide a hydrogen fuel supply system in which nearly all the hydrogen stored in the storage tank before the tank has to be recharged.

### SUMMARY OF THE INVENTION

The foregoing objective was achieved in accordance with this invention by providing a hydrogen fuel supply system which is effective in delivering sufficient hydrogen to the engine to permit normal operation thereof with storage tank pressures as low as about 5 psig by minimizing the pressure drop incurred in transferring the hydrogen from the storage tank to the feed means for feeding gaseous hydrogen to the intake manifold of the engine, i.e., the mixing device which mixes the hydrogen with air and introduces the mixture to the intake manifold.

The fuel system of this invention comprises, in combination with an internal combustion engine having feed

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means for feeding gaseous hydrogen to the intake manifold thereof, a fuel tank containing a metal hydride which is capable of reacting with and absorbing hydrogen at a given temperature and pressure, and of releasing hydrogen gas at a temperature higher than the given temperature and/or a pressure lower than the given pressure. A supply conduit is connected between the fuel tank and the feed means to the intake manifold of the engine for flow of gaseous hydrogen from the fuel tank to the feed means. A bypass conduit has one end connected to the supply conduit at some point between the tank and the feed means, with the other end of the bypass conduit being reconnected to the supply conduit downstream from the first connection. A pressure regulator is provided in conjunction with the bypass conduit. The pressure regulator is adapted to regulate the pressure downstream thereof at a preset value when the upstream pressure is greater than the preset value, and of allowing the downstream pressure to decrease below the preset value when the upstream pressure is below the preset value.

Valve means are provided in combination with the supply conduit and the bypass conduit. The valve means are adapted to either direct the flow of hydrogen gas directly through the supply conduit or to divert the flow of hydrogen gas from the supply conduit through the bypass conduit and back to the supply conduit downstream from the valve means. During the majority of an operation cycle of a fully charged storage tank, hydrogen is discharged from the tank at relatively high pressures, i.e., from about 150 to 500 psig. During this period, the valve means are controlled so as to divert the flow of hydrogen through the bypass conduit and the pressure regulator which regulates the downstream pressure of the hydrogen to a value no greater than can adequately be handled by the downstream apparatus, principally the feed means which introduces the hydrogen to the intake manifold of the engine. When the upstream pressure, i.e., the pressure of the hydrogen coming from the storage tank, declines to a level which is inadequate to supply a full flow of hydrogen because of the pressure drop through the bypass conduit and pressure regulator, the valve means are controlled so as to direct the flow of hydrogen gas directly through the low-pressure-drop supply conduit and thus avoid the bypass conduit and its associated high pressure drop requirements. By avoiding the high pressure drop, an adequate flow of hydrogen can be supplied to the engine even when the pressure of the hydrogen coming from the storage tank has declined to around 5 psig.

A pressure actuated controller is adapted to monitor the pressure of the hydrogen in the bypass conduit or supply conduit downstream from the regulator and controls the valve means in accordance with the monitored pressure. The pressure at which the controller charges the valve means for flow of hydrogen directly through the supply conduit and avoid the bypass conduit can be set at any preset level which is no greater than the preset pressure of the regulator but still large enough that full flow of hydrogen can be delivered through the bypass conduit at that pressure. It has been found advantageous to set the control pressure of the controller at between about 50 to 100 psig.

Preferably, means are also provided in combination with the controller whereby the valve means can be closed thereby preventing hydrogen gas flow through either the supply conduit or bypass conduit. This per-

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mits charging of the storage tanks at high pressure without subjecting the downstream supply conduit, the bypass conduit, and the feed means on the engine to such high pressure.

### THE DRAWING

A particular embodiment of the present invention representing the best mode presently contemplated of carrying out the invention is illustrated in the accompanying drawing consisting of a single figure showing a hydrogen fuel supply system for use with an internal combustion engine of a motor vehicle.

### DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

In accordance with the present invention, a hydrogen supply system is provided in combination with an internal combustion engine. In the drawing, an engine 11 of a motor vehicle is shown. A fuel supply conduit 10 connects the storage tank 12 with a carburetor 17 which is adapted to receive gaseous hydrogen from the conduit 10 and to mix the hydrogen gas with air for introduction to the intake manifold of the engine 11. Exemplary carburetors suitable for use with internal combustion engines are disclosed in U.S. Pat. No. 3,983,882, issued to Roger E. Billings on Oct. 5, 1976.

The storage tank 12 contains a metal material which is capable of reacting with and absorbing hydrogen at a given temperature and pressure in the form of a metal hydride, and the metal hydride is capable of dissociating and thereby releasing hydrogen when by raising the temperature above the given temperature at which the hydrogen was absorbed and/or reducing the given pressure at which the hydrogen was absorbed. Exemplary metal materials which can be utilized include iron, titanium, nickel, calcium, magnesium, manganese, rare earth elements, and mixtures and alloys thereof. Alloys which are particularly advantageous include iron-titanium, lanthanum-nickel, calcium-nickel, mischmetal-nickel, manganese-nickel, and mischmetal-calcium-nickel alloys. The storage tank 12 is adapted to hold the metal material therein and to enable the circulation of a heat exchange medium in proximity with the metal material. Exemplary storage tank configurations are shown in U.S. Pat. No. 4,016,836, issued to Donald B. MacKay et al. on Apr. 12, 1977. As shown in the drawing the exhaust manifold 14 is coupled by way of a bidirectional valve 13 to a conduit 15 to the tank 12, and to an exhaust pipe 16 leading to a muffler 18 and another section of exhaust pipe 19. The valve 13 is adapted to direct exhaust gases from the manifold 14 either through conduit 15 to the storage tank 12, or to pipe 16 for discharge into the atmosphere, or to both. The exhaust gases introduced into tank 12 through conduit 15 are exhausted therefrom through pipe 20. The operation of valve 13 and the exhaust system are fully described in the above-mentioned MacKay et al. Patent.

The hydrogen supply conduit 10 provides direct flow of gaseous hydrogen from tank 12 to carburetor 17 during certain stages of the operation of tank 12 as will be explained further hereinbelow. A bypass conduit 21 is connected at one of its ends (the upstream end) to the supply conduit 10 at a point between the tank 12 and carburetor 17, with its other end (downstream end) reconnected to the supply conduit 10 downstream from the first connection.

Valve means are provided in combination with supply conduit 10 and bypass conduit 21 so as to either

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direct the flow of hydrogen gas directly through the supply conduit 10 or to divert the flow of hydrogen gas from the supply conduit 10 through the bypass conduit 21 and back to the supply conduit 10 downstream from the valve means. As shown in the drawing, the valve means comprises first and second valves 22 and 23 in spaced relationship, with the first valve 22 being upstream from the first connection of the bypass conduit 21, and the second valve is located in the portion of the supply conduit 10 between the connections of the bypass conduit 21. When valve 23 is closed and valve 22 is open, the flow of hydrogen is directed through the bypass conduit 21. When both valves 22 and 23 are open, the flow of hydrogen is directed through conduit 10 directly to the carburetor 17.

A pressure regulator 24 is provided in combination with bypass conduit 21 and is capable of regulating the pressure downstream thereof at a preset value when the pressure upstream thereof is greater than the preset value, and of allowing the downstream pressure to decrease below the preset value when the pressure upstream is below the preset value. Thus, when hydrogen is obtained from the storage tank 12 at pressures above the preset value, say 150 psig, the regulator maintains a pressure of 150 psig, the preset value, in the downstream portion of conduits 21 and 10. As the pressure of the hydrogen coming from tank 12 drops to less than 150 psig, the regulator 24 allows hydrogen flow there-through with a downstream pressure considerably less than the preset value or of the upstream pressure.

A pressure actuated controller is adapted to monitor the pressure downstream of the regulator 24 and to control the operation of the valve means and thereby the direction of flow of hydrogen through the system. As illustrated, the controller 25 is positioned in the downstream portion of bypass conduit 21 prior to the reconnection of that conduit with the supply conduit 10. The controller 25 is supplied with a source of electrical current, such as from a remote switch 26. The switch 26 is advantageously the ignition switch for the engine and is adapted to supply an electrical current to controller 25 when the ignition switch is in any position except the off position. The controller 25 is advantageously a pressure activated switch which is closed at a selected pressure which is less than the preset value of regulator 24. The selected pressure for controller 25 can be in the range of from about 20 to 100 psig, preferably from about 50 to 100 psig. When the switch of controller 25 closes, electrical current is provided to a solenoid 27 on valve 23. When the solenoid 27 is energized, it opens valve 23. Otherwise, valve 23 is adapted to close automatically under spring force whenever the solenoid 27 is not energized. Thus, when the pressure downstream of controller 25 is above the set pressure thereof, no current is supplied to solenoid 27 and valve 23 remains closed, so that hydrogen gas is directed through bypass conduit 21. But, when the downstream pressure falls below the set pressure of controller 25, an electrical current is supplied to solenoid 27 and valve 23 opens, so that hydrogen gas can pass directly through conduit 10 to carburetor 17. The pressure drop through conduit 10 is designed to be minimal and significantly less than the pressure drop incurred through the regulator 24. Thus, by avoiding the higher pressure drops associated with a system containing a pressure regulator, a significantly larger amount of hydrogen can be withdrawn from the storage tank 12 in sufficient amount to operate the engine 11 before refilling of tank 12 is required. In addition,

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tion, a much lower grade metal material can be utilized in the tank 12. The lower grade material still contains significant amounts of hydrogen at low pressures, and this hydrogen can be utilized with the supply system of this invention.

The valve 22 is provided to primarily protect the fuel supply system downstream thereof from high pressures which are used in recharging or refilling of the tank 12. Valve 22 is similar to valve 23 in that it is operated by a solenoid 28 and it is adapted to close automatically under spring force when the solenoid 28 is not energized. The solenoid 28 is provided with a source of electrical current by a remote switch, preferably the ignition switch 26 of the engine. When the ignition switch is in the off position, valve 22 is closed, and when the ignition switch is turned on, the solenoid 28 is energized and valve 22 is opened.

As illustrated, the ignition switch 26 is connected by electrical circuits 29 and 30 to controller 25 and solenoid 28, respectively. The controller 25 is in turn in electrical connection with solenoid 27 through circuit 31. The system could be modified by replacing valves 22 and 23 with a single 3-way valve at the upstream connection of the bypass conduit 21 to supply conduit 10. The 3-way valve would be of the type which are spring biased in a closed position when the solenoids associated therewith are not energized. The controller 25 would energize the solenoid opening the valve to the bypass conduit 21 when the pressure of gas coming from the tank 12 was sufficient that the pressure downstream of the regulator 24 was greater than the set pressure of the controller. When the pressure downstream of the regulator falls to a value less than the set pressure, the controller would energize the solenoid so that valve would open to the supply conduit 10. Other modifications could be made and other embodiments constructed without departing from the novel inventive concepts set forth herein and in the claims which follow.

We claim:

1. A hydrogen fuel supply system in combination with an internal combustion engine having feed means for feeding gaseous hydrogen to the intake manifold thereof, said fuel system comprising:

- a fuel tank containing a metal hydride which is capable of reacting with and adsorbing hydrogen at a given temperature and pressure, and of releasing hydrogen gas at least under one of the conditions of a temperature higher than said given temperature or a pressure lower than said given pressure;
- a supply conduit connected between said fuel tank and said feed means of said engine for flow of gaseous hydrogen from said fuel tank to said feed means;
- a bypass conduit having one end thereof connected to the supply conduit at a point between said tank and said feed means, and having its other end connected to the supply conduit downstream from the connection of said one end to said supply conduit;
- a pressure regulator in combination with said bypass conduit, said pressure regulator being capable of regulating the pressure downstream thereof at a preset value when the pressure upstream thereof is greater than the preset value and of allowing the pressure downstream to decrease below the preset value when the pressure upstream is below the preset value;

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valve means in combination with the supply conduit and the bypass conduit, said valve means being adapted to either direct the flow of hydrogen gas directly through the supply conduit or to divert the flow of hydrogen gas from the supply conduit through the bypass conduit and back to the supply conduit downstream from the valve means;

a pressure actuated controller adapted to monitor the pressure downstream from said regulator, said controller also being adapted to control said valve means so that hydrogen flows through the bypass conduit when the monitored pressure is greater than a second preset pressure of said regulator, and said controller also being adapted to control said valve means so that hydrogen flows directly through the supply conduit when the monitored pressure is less than said second preset pressure.

2. A hydrogen fuel supply system in accordance with claim 1, wherein said valve means can also be closed thereby preventing hydrogen gas flow through either the supply conduit or the bypass conduit, and means are provided in combination with said controller for closing said valve means.

3. A hydrogen fuel supply system in accordance with claim 2, wherein the means for closing said valve means comprises a remote switch which when moved to its off position terminates the operation of the controller, and the valve means is provided with means for returning to its normally closed position when the operation of the controller is terminated.

4. A hydrogen fuel supply system in accordance with claim 3, wherein the controller is rendered operational by providing an electric current thereto, and the switch is the ignition switch on the internal combustion engine, said ignition switch being connected to said controller through an electrical circuit so that when the ignition switch is in any position other than off, electrical current is supplied to the controller.

5. A hydrogen fuel supply system in accordance with claim 4, wherein the valve means is provided with at least one solenoid which is adapted to operate the valve means when supplied with an electrical current, and the controller is a pressure activated switch which is adapted to close and thereby allow electrical current to pass to the solenoid when the monitored pressure is less than said second preset measure, with said pressure activating switch being open, thereby preventing current flow to the solenoid when the monitored pressure is greater than the second preset pressure.

6. A hydrogen fuel supply system in accordance with claim 1, wherein the valve means comprises first and second valves positioned in spaced relationship in the supply conduit, with the first valve being upstream from said one end of the bypass conduit and the second valve being positioned in the portion of the supply conduit between the connections of the bypass conduit;

said controller is adapted to maintain the second valve closed when the monitored pressure is greater than said second preset pressure, and to maintain the second valve open when the monitored pressure is less than said second preset pressure; and

said switch means is adapted to maintain the first valve open when the switch means is in the on position and to maintain the first valve closed when the switch means is in the off position.

7. A hydrogen fuel supply system in accordance with claim 6, wherein each of said first and second valves has

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a solenoid in combination therewith which is adapted to open its respective valve when it is supplied with an electrical current, with said valves being adapted to automatically return to their closed position when the current to the respective solenoids is discontinued;

5 said controller comprises a pressure activated switch which is adapted to close and thereby allow electrical current to pass to the solenoid on the second valve when the monitored pressure is less than said second preset pressure, said pressure activating switch being open, thereby preventing current

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flow to the solenoid when the monitored pressure is greater than the second preset pressure; and said switch completing an electrical circuit which provides current to said pressure activated switch when the switch means is in the on position and breaks the circuit when in the off position.

8. A hydrogen fuel supply system in accordance with claim 6, wherein the switch is incorporated into the ignition switch of the engine.

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**United States Patent** [19]

[11]

**4,182,748****Anderson****Best Available Copy**

[45]

**Jan. 8, 1980**

[54] **MATERIAL AND METHOD FOR  
OBTAINING HYDROGEN AND OXYGEN BY  
DISSOCIATION OF WATER**

3,313,598	4/1967	Glukstein .....	423/657 X
3,490,871	1/1970	Miller et al. ....	423/657
3,540,854	11/1970	Brooke et al. ....	423/657 X
3,833,357	9/1974	Bianchi et al. ....	423/457 X
3,985,866	10/1976	Oda et al. ....	423/657

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[21] **Appl. No.:** 902,708

[57]

**ABSTRACT**

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[51] **Int. Cl.<sup>2</sup>** ..... C01B 13/02; C01B 1/07

[52] **U.S. Cl.** ..... 423/579; 75/134 N;  
75/134 A; 75/138; 423/657

[58] **Field of Search** ..... 423/579, 657; 75/134 A,  
75/138, 169, 134 N; 252/372

A material and method for the decomposition/dissocia-  
tion of water into hydrogen and oxygen is disclosed.  
The material comprises an amalgam of an alkali metal,  
mercury, and aluminum combined with a catalytically  
effective amount of an alloy comprising platinum and at  
least one metal selected from the group consisting of  
germanium, antimony, gallium, thallium, indium, cad-  
mium, bismuth, lead, zinc and tin.

[56] **References Cited**

**U.S. PATENT DOCUMENTS**

2,837,408 6/1958 Skaowski ..... 423/657 X

**29 Claims, No Drawings**



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# MATERIAL AND METHOD FOR OBTAINING HYDROGEN AND OXYGEN BY DISSOCIATION OF WATER

## BACKGROUND OF THE INVENTION

### 1. Field of Invention

This invention relates to a material for and method of effecting the decomposition/dissociation of water into hydrogen and oxygen.

The water is reacted with an amalgam of sodium, aluminum and mercury to form hydrogen and a metallic hydroxide denoted by the formula  $\text{Na}_3\text{Al}(\text{OH})_6$ . The  $\text{Na}_3\text{Al}(\text{OH})_6$  is unstable at the temperature of formation in the presence of a catalyst comprising platinum and at least one element selected from the group consisting of germanium, antimony, gallium, thallium, indium, cadmium, bismuth, lead, zinc and tin and breaks down to form metallic sodium and aluminum thereby releasing oxygen and hydrogen.

### 2. Description of the Prior Art

It is well known in the prior art that the alkali metals react with water to form hydrogen and the stable alkali metal hydroxide. The foregoing reaction is rapid, the heat generated intense and explosion of hydrogen ordinarily occurs. The result is an unsatisfactory and dangerous method of generating hydrogen. It is also well known that alkali metal peroxides may be used for the generation of oxygen (see U.S. Pat. No. 3,574,561).

Thermochemical cycles comprising metal-metalloid combinations for the generation of both hydrogen and oxygen are disclosed in U.S. Pat. No. 3,969,495.

Closed cycle processes for dissociation of water into hydrogen and oxygen are disclosed in U.S. Pat. Nos. 3,821,358, 3,928,549 and 4,011,305. Combinations of various metals in multistep processes for dissociation of water are, therefore, well known; however, the simple and facile manner of producing hydrogen and oxygen utilizing an amalgam of alkali metal, aluminum and mercury combined with a catalytic alloy comprising platinum and at least one element selected from the group consisting of germanium, antimony, gallium, thallium, indium, cadmium, bismuth, lead, zinc and tin has not been heretofore appreciated.

## DESCRIPTION OF THE INVENTION

The material I have found to be suitable for the generation of hydrogen and oxygen from water without spontaneous combustion of the resultant evolved hydrogen and oxygen gases comprises an amalgam of (1) an alkali metal such as lithium, sodium, potassium, cesium, or combinations thereof, (2) aluminum and (3) mercury combined with a catalytic alloy comprising platinum and at least one element selected from the group consisting of germanium, antimony, gallium, thallium, indium, cadmium, bismuth, lead, zinc and tin.

The particle size of the sodium and aluminum is such as to enable formation of an amalgam and may fall within the range of from about 10 to about 100 mesh. Most preferably, the particle size of the aluminum should be about 10 mesh. Alkali metal of  $\frac{1}{4}$ " diameter is suitable. The particle size of either the alkali metal or aluminum is not critical since the foregoing metals and mercury readily intermix. The smaller the particle size, of course, the more rapid the mixing.

The atomic weight ratio of alkali metal to mercury is from about 1:100 to about 100:1 and the atomic weight ratio of alkali metal to aluminum is from about 1:100 to

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about 100:1. Preferably the atomic weight ratio of alkali metal to mercury is from about 3:1 to about 1:1.5 and the atomic weight ratio of alkali metal to aluminum is from about 1:1 to about 3:1.

The amalgam of alkali metal, aluminum and mercury is combined with a catalytically active alloy which is present in a catalytically effective amount and, at the conditions of hydrogen generation, functions to regenerate amalgam to the active metallic state.

It is essential that the catalyst/alloy contain a platinum group metal and specifically platinum. The catalyst/alloy is generally comprised of platinum and at least one element selected from the group consisting of germanium, antimony, gallium, thallium, indium, cadmium, bismuth, lead, zinc and tin.

Preferably the catalyst comprises platinum and at least one element selected from the group consisting of germanium, antimony, gallium, thallium, indium and cadmium.

Catalytic activity is further enhanced by the addition of minor amounts of zirconium and chromium.

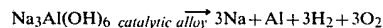
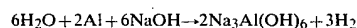
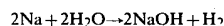
Lead and/or gold may be incorporated in the catalyst as an alloying element to lower the melting point of the alloy.

The alloy and amalgam may be combined in weight ratios of from about 1:1 to about 1:5 and preferably from about 1:2 to about 1:3.

In combining the alloy and amalgam they may be compounded with an extender. The extender functions both to dilute the amalgam-catalytic alloy combination and to provide a heat sink for heat generated during the dissociation of water by contact with the combined amalgam and catalytic alloy. The extender is preferably copper; however, admixtures of tin and bismuth or gallium may also function as extenders.

The combination of amalgam and alloy or amalgam, alloy and extender is most suitably used in solid block form, hereinafter referred to as a reactor block. Where an extender is employed it may be present as a major constituent of the reactor block.

Although not wishing to be bound by the following explanation, it is believed that the water reacts with the alkali metal, e.g., sodium, and the aluminum liberating hydrogen and forming  $\text{Na}_3\text{Al}(\text{OH})_6$ . The  $\text{Na}_3\text{Al}(\text{OH})_6$  is unstable, and in the presence of the alloy at the conditions of  $\text{Na}_3\text{Al}(\text{OH})_6$  formation, the foregoing composition decomposes to form  $\text{H}_2$ ,  $\text{O}_2$  and regenerate amalgam. The alloy apparently functions to catalyze the decomposition, and thereby extends the useful life of the amalgam. The process may be depicted as follows:



It is preferred to include chromium as an additional component of the alloy. The incorporation of chromium as a component of the alloy appears to lower the heat of reaction. The chromium is generally present in the alloy in an amount measured on a weight percent basis of said alloy of from about 0.7% to about 1.1% and preferably for about 0.8% to about 0.9%.

Each of the components of the alloy may be present in amounts of from about 0.4% by weight to about

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28.5% by weight based on the weight of the combined catalytic alloy and amalgam.

The preferred alloy comprises (1) platinum present in an amount of from about 0.7 to about 1.1% by weight, (2) lead present in an amount of from about 42.9 to about 71.5% by weight, (3) antimony present in an amount of from about 25.5 to about 42.5% by weight, (4) chromium present in an amount of from about 0.7 to about 1.1% by weight, (5) zirconium present in an amount of from about 4.1 to about 6.8% by weight and gold present in an amount of from about 1.1 to about 1.9% by weight.

A specific example of the alloy comprises about 0.9 wt. % platinum, about 57.3 wt. % lead, about 34.0 wt. % antimony, about 0.9 wt. % chromium, about 5.4 wt. % zirconium and about 1.5 wt. % gold.

The amalgam of sodium, aluminum and mercury is prepared utilizing any of the well known procedures with the added proviso that an inert atmosphere be employed. Amalgamation may be facilitated by utilization of an elevated temperature, preferably around 200° C.  $\pm 10^\circ$  C. The amalgam is preferably maintained at this elevated temperature for about 10 minutes where 100 grams are being processed, and the time is extended about 1 minute for each additional 100 gram aliquot.

The resulting amalgam is cooled, generally to room temperature, utilizing an inert atmosphere. For this purpose either helium or nitrogen are satisfactory. Cooling is preferably effected in a desiccator to insure that no water contacts the amalgam.

As in the preparation of the amalgam and all other steps in the method of manufacture of the various compositions of this invention, precaution must be taken during preparation to avoid the presence of oxygen because it has been observed that oxygen operates to poison the resultant material.

The preparation of the alloy selected may be in any well known manner having in mind the proviso that an inert atmosphere be maintained.

The alloy, upon solidification, and as a practical matter, upon cooling is ground into a powder, preferably a fine powder of about 10 mesh or less. Cooling may be effected in a desiccator to insure the absence of oxygen and moisture, whose presence is detrimental during preparation. Grinding/pulverizing may be effected in any well known manner including use of a ball, hammer and/or stamp mill.

The objective in combining the alloy and amalgam is to intimately admix the two respective components. The specific manner of catalysis is not known, but generally catalysis is a surface phenomenon and consistent therewith in the instant invention it appears that the catalysis is related to both particle size and nature as well as uniformity of mixture of the amalgam and catalytic alloy.

The amalgam and catalytic alloy may be used (1) in particulate form such as a floating bed, or other intimate dispersion, (2) in the form of porous mass which may be formed by compression or sintering or (3) as a solid mass by allowing of the amalgam and catalytic alloy. By alloying, it is meant that the amalgam and catalytic alloy are combined to form an admixture and alloyed under inert conditions at a temperature above the melting point of said admixture.

In either of the foregoing forms an extender, such as gallium, tin, bismuth or copper, and preferably copper may be utilized. The extender functions to vary activity and as a heat sink to retain at least a portion of the heat

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of reaction of sodium aluminum hydroxide formation, whereby catalysis of the unstable hydroxide to the metal and oxygen and hydrogen is enhanced.

Admixture of extender with the amalgam and catalytic alloy is effected utilizing the extender in a particulate form of comparable size to the other components, which size is generally from about 10 to about 100 mesh.

### EXAMPLE I

#### Preparation of Amalgam

An amalgam comprising 35.144 parts by weight of sodium, 13.749 parts by weight of aluminum and 51.107 parts by weight of mercury is formed in a graphite crucible in an inert atmosphere of nitrogen at an elevated temperature of 200° C.

The resulting amalgam is cooled to room temperature in a dessicator in an inert nitrogen atmosphere. Thereafter, the amalgam is formed into a fine powder of about 10 mesh utilizing a ball mill. Grinding is effected in an inert atmosphere of nitrogen.

It is important to prepare the amalgam in an inert gas atmosphere to prevent hydroxide formation.

#### Preparation of Catalytic Alloy

19.0 Parts by weight lead, 11.3 parts by weight antimony, 0.3 parts by weight platinum, 0.5 parts by weight gold, 1.8 parts by weight zirconium and 0.3 parts by weight chromium are introduced into a graphite crucible which is thereafter placed in an oven and heated to melting in an inert atmosphere of helium to form an alloy of said metals.

The resulting alloy is cooled in a dessicator to about room temperature in an inert helium atmosphere. Thereafter the amalgam is formed into a fine powder of about 10 mesh or less utilizing a ball mill. Grinding is effected in an inert atmosphere of helium.

The inert atmosphere is used to prevent oxidation of the alloy.

#### Formation of Intimate Amalgam and Catalytic Alloy Admixture

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy in an inert atmosphere to obtain a uniform mixture of the amalgam and catalytic alloy.

The admixture may be utilized by passing steam upwardly therethrough whereby steam is dissociated into hydrogen and oxygen.

#### Formation of Reactor Block Comprising Amalgam and Catalytic Alloy

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy. The weighing and blending is effected in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product. The mold utilized produces a cubical block.

The resulting block is heated to an elevated temperature of about 10° C. above the melting point of the mass and maintained at said temperature for about 10  $\pm$  1 minutes. In the oven utilized for heating, an inert atmosphere, is maintained. Thereafter the mass comprised of amalgam and alloy is transferred to a dessicator wherein

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an inert atmosphere is maintained and the mass is allowed to cool. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out in an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

#### Formation of Reactor Block Comprising Amalgam, Catalytic Alloy and Extender

The amalgam and alloy prepared above and an extender of powdered copper of about 10 mesh are admixed in the following proportions:

21.775 parts by weight amalgam.

5.625 parts by weight alloy.

72.6 parts by weight copper (extender).

The weighing and blending of the foregoing metallic compounds should be done in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product. The compressed mass in a crucible conforming to the shape thereof is heated to an elevated temperature of about 10° C. above the melting point of the mass and this temperature is maintained for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the crucible and its contents are transferred to a desiccator wherein an inert atmosphere is maintained. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out under an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

The reactor blocks are contacted with a fine spray of water at about room temperature in an atmospheric environment. The gaseous effluent from said contact comprises hydrogen and oxygen and burns when subjected to electrical sparking. The volume of gas evolved is dependent on reactor block surface area and the volume of water impinging thereon. Generally a 2.5 square cm surface will react with 0.14 gallons of water per minute.

#### EXAMPLE II

##### Preparation of Amalgam

An amalgam comprising 37.688 parts by weight of aluminum, 32.112 parts by weight sodium and 30.2 parts by weight mercury is formed in a graphite crucible in an inert atmosphere of nitrogen at an elevated temperature of 200° C.

The resulting amalgam is cooled to room temperature in a desiccator in an inert nitrogen atmosphere. Thereafter, the amalgam is formed into a fine powder of about 10 mesh utilizing a ball mill. Grinding is effected in an inert atmosphere of nitrogen.

It is important to prepare the amalgam in an inert gas atmosphere to prevent hydroxide formation.

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##### Preparation of Catalytic Alloy

60.7 Parts by weight lead, 0.8 parts by weight platinum and 38.5 parts by weight germanium are introduced into a graphite crucible which is thereafter placed in an oven and heated to melting in an inert atmosphere of helium to form an alloy of said metals.

The resulting alloy is cooled in a dessicator to about room temperature in an inert helium atmosphere. Thereafter the amalgam is formed into a fine powder of about 10 mesh or less utilizing a ball mill. Grinding is effected in an inert atmosphere of helium.

The inert atmosphere is used to prevent oxidation of the alloy.

##### Formation of Intimate Amalgam and Catalytic Alloy Admixture

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy in an inert atmosphere to obtain a uniform mixture of the amalgam and catalytic alloy.

The admixture may be utilized by passing steam upwardly therethrough whereby steam is dissociated into hydrogen and oxygen.

##### Formation of Reactor Block Comprising Amalgam and Catalytic Alloy

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy. The weighing and blending is effected in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product. The mold utilized produces a cubical block.

The resulting block is heated to an elevated temperature of about 10° C. above the melting point of the mass and maintained at said temperature for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the mass comprised of amalgam and alloy is transferred to a dessicator wherein an inert atmosphere is maintained and the mass is allowed to cool. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out in an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

##### Formation of Reactor Block Comprising Amalgam, Catalytic Alloy and Extender

The amalgam and alloy prepared above and an extender of powdered copper of about 10 mesh are admixed in the following proportions:

21.775 parts by weight amalgam.

5.625 parts by weight alloy.

72.6 parts by weight copper.

The weighing and blending of the foregoing metallic compounds should be done in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per

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square inch in a graphite mold conforming to the desired shape of the finished product.

The compressed mass in a crucible conforming to the shape thereof is heated to an elevated temperature of about 10° C. above the melting point of the mass and this temperature is maintained for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the crucible and its contents are transferred to a desiccator wherein an inert atmosphere is maintained. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out under an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

The reactor blocks are contacted with a fine spray of water at about room temperature in an atmospheric environment. The gaseous effluent from said contact comprises hydrogen and oxygen and burns when subjected to electrical sparking. The volume of gas evolved is dependent on reactor block surface area and the volume of water impinging thereon. Generally a 2.5 square cm surface will react with 0.20 gallons of water per minute.

### EXAMPLE III

#### Preparation of Amalgam

An amalgam comprising 22.947 parts by weight of aluminum, 18.391 parts by weight sodium and 58.662 parts by weight mercury is formed in a graphite crucible in an inert atmosphere of nitrogen at an elevated temperature of 200° C.

The resulting amalgam is cooled to room temperature in a desiccator in an inert nitrogen atmosphere. Thereafter, the amalgam is formed into a fine powder of about 10 mesh utilizing a ball mill. Grinding is effected in an inert atmosphere of nitrogen.

It is important to prepare the amalgam in an inert gas atmosphere to prevent hydroxide formation.

#### Preparation of Catalytic Alloy

63.064 Parts by weight lead, 0.45 parts by weight platinum, 36.036 parts by weight antimony and 0.45 parts by weight germanium are introduced into a graphite crucible which is thereafter placed in an oven and heated to melting in an inert atmosphere of helium to form an alloy of said metals.

The resulting alloy is cooled in a desiccator to about room temperature in an inert helium atmosphere. Thereafter the amalgam is formed into a fine powder of about 10 mesh or less utilizing a ball mill. Grinding is effected in an inert atmosphere of helium.

The inert atmosphere is used to prevent oxidation of the alloy.

#### Formation of Intimate Amalgam and Catalytic Alloy Admixture

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy in an inert atmosphere to obtain a uniform mixture of the amalgam and catalytic alloy.

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The admixture may be utilized by immersion in water whereby water is dissociated into hydrogen and oxygen.

#### 5 Formation of Reactor Block Comprising Amalgam and Catalytic Alloy

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy. The weighing and blending is effected in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product. The mold utilized produces a cubical block.

The resulting block is heated to an elevated temperature of about 10° C. above the melting point of the mass and maintained at said temperature for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the mass comprised of amalgam and alloy is transferred to a desiccator wherein an inert atmosphere is maintained and the mass is allowed to cool. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out in an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

#### 35 Formation of Reactor Block Comprising Amalgam, Catalytic Alloy and Extender

The amalgam and alloy prepared above and a powdered extender comprising 50 wt.% tin and 50 wt.% bismuth of about 10 mesh are admixed in the following proportions:

21.775 parts by weight amalgam

5.625 parts by weight alloy

72.6 parts by weight extender

The weighing and blending of the foregoing metallic compounds should be done in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product.

The compressed mass in a crucible conforming to the shape thereof is heated to an elevated temperature of about 10° C. above the melting point of the mass and this temperature is maintained for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the crucible and its contents are transferred to a desiccator wherein an inert atmosphere is maintained. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out under an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

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The reactor blocks are contacted with a fine spray of water at about room temperature in an atmospheric environment. The gaseous effluent from said contact comprises hydrogen and oxygen and burns when subjected to electrical sparking. The volume of gas evolved is dependent on reactor block surface area and the volume of water impinging thereon. Generally a 2.5 square cm surface will react with 0.12 gallons of water per minute.

#### EXAMPLE IV

##### Preparation of Amalgam

An amalgam comprising 19.383 parts by weight aluminum, 31.068 parts by weight potassium and 49.549 parts by weight mercury is formed in a graphite crucible in an inert atmosphere of nitrogen at an elevated temperature of 200° C.

The resulting amalgam is cooled to room temperature in a dessicator in an inert nitrogen atmosphere. Thereafter, the amalgam is formed into a fine powder of about 10 mesh utilizing a ball mill. Grinding is effected in an inert atmosphere of nitrogen.

It is important to prepare the amalgam in an inert gas atmosphere to prevent hydroxide formation.

##### Preparation of Catalytic Alloy

42.847 Parts by weight lead, 2.429 parts by weight platinum, 42.847 parts by weight antimony, 2.429 parts by weight cadmium and 9.448 parts by weight zirconium are introduced into a graphite crucible which is thereafter placed in an oven and heated to melting in an inert atmosphere of helium to form an alloy of said metals.

The resulting alloy is cooled in a dessicator to about room temperature in an inert helium atmosphere. Thereafter the amalgam is formed into a fine powder of about 10 mesh or less utilizing a ball mill. Grinding is effected in an inert atmosphere of helium.

The inert atmosphere is used to prevent oxidation of the alloy.

##### Formation of Intimate Amalgam and Catalytic Alloy Admixture

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy in an inert atmosphere to obtain a uniform mixture of the amalgam and catalytic alloy.

The admixture may be utilized by spraying water on the admixture whereby water is dissociated into hydrogen and oxygen.

##### Formation of Reactor Block Comprising Amalgam and Catalytic Alloy

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy. The weighing and blending is effected in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product. The mold utilized produces a cubical block.

The resulting block is heated to an elevated temperature of about 10° C. above the melting point of the mass and maintained at said temperature for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere, is maintained. Thereafter the mass comprised of

amalgam and alloy is transferred to a dessicator wherein an inert atmosphere is maintained and the mass is allowed to cool. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out in an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

##### Formation of Reactor Block Comprising Amalgam, Catalytic Alloy and Extender

The amalgam and alloy prepared above and an extender of powdered gallium of about 10 mesh are admixed in the following proportions:

21.775 parts by weight amalgam

5.625 parts by weight alloy

72.6 parts by weight gallium.

The weighing and blending of the foregoing metallic compounds should be done in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product.

The compressed mass in a crucible conforming to the shape thereof is heated to an elevated temperature of about 10° C. above the melting point of the mass and this temperature is maintained for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter, the crucible and its contents are transferred to a dessicator wherein an inert atmosphere is maintained. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out under an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

The reactor blocks are contacted with a fine spray of water at about room temperature in an atmospheric environment. The gaseous effluent from said contact comprises hydrogen and oxygen and burns when subjected to electrical sparking. The volume of gas evolved is dependent on reactor block surface area and the volume of water impinging thereon. Generally, a 2.5 square cm surface will react with 0.14 gallons of water per minute.

#### EXAMPLE V

##### Preparation of Amalgam

An amalgam comprising 37.688 parts by weight aluminum, 32.112 parts by weight cesium and 30.2 parts by weight mercury is formed in a graphite crucible in an inert atmosphere of nitrogen at an elevated temperature of 200° C.

The resulting amalgam is cooled to room temperature in a dessicator in an inert nitrogen atmosphere. Thereafter, the amalgam is formed into a fine powder of about 10 mesh utilizing a ball mill. Grinding is effected in an inert atmosphere of nitrogen.

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It is important to prepare the amalgam in an inert gas atmosphere to prevent hydroxide formation.

#### Preparation of Catalytic Alloy

60.7 Parts by weight lead, 0.8 parts by weight platinum and 38.5 parts by weight germanium are introduced into a graphite crucible which is thereafter placed in an oven and heated to melting in an inert atmosphere of helium to form an alloy of said metals.

The resulting alloy is cooled in a dessicator to about room temperature in an inert helium atmosphere. Thereafter the amalgam is formed into a fine powder of about 10 mesh or less utilizing a ball mill. Grinding is effected in an inert atmosphere of helium.

The inert atmosphere is used to prevent oxidation of the alloy.

#### Formation of Intimate Amalgam and Catalytic Alloy Admixture

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy in an inert atmosphere to obtain a uniform mixture of the amalgam and catalytic alloy.

The admixture may be utilized by passing steam upwardly therethrough whereby steam is dissociated into hydrogen and oxygen.

#### Formation of Reactor Block Comprising Amalgam and Catalytic Alloy

Three parts by weight of powdered amalgam is admixed with one part by weight powdered alloy. The weighing and blending is effected in an inert atmosphere.

After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product. The mold utilized produces a cubical block.

The resulting block is heated to an elevated temperature of about 10° C. above the melting point of the mass and maintained at said temperature for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the mass comprised of amalgam and alloy is transferred to dessicator wherein an inert atmosphere is maintained and the mass is allowed to cool. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out in an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

#### Formation of Reactor Block Comprising Amalgam, Catalytic Alloy and Extender

The amalgam and alloy prepared above and an extender of powdered copper of about 10 mesh are admixed in the following proportions:

21.775 by weight amalgam

5.625 parts by weight alloy

72.6 parts by weight copper

The weighing and blending of the foregoing metallic compounds should be done in an inert atmosphere.

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After blending to provide a uniform mixture, the resultant mixture is compressed to form a solid mass by application of pressure of about 40,000 pounds per square inch in a graphite mold conforming to the desired shape of the finished product.

The compressed mass in a crucible conforming to the shape thereof is heated to an elevated temperature of about 10° C. above the melting point of the mass and this temperature is maintained for about 10±1 minutes. In the oven utilized for heating, an inert atmosphere is maintained. Thereafter the crucible and its contents are transferred to a dessicator wherein an inert atmosphere is maintained. Upon cooling the resultant block is ready for use.

The entire foregoing procedure should be carried out under an inert atmosphere such as helium or nitrogen and in the absence of contaminants. Oxidation of the metallic components and/or hydroxide formation will "poison" the resulting reactor block and reduce the activity thereof. Moreover, during the steps of the process operated at elevated temperature, the presence of any oxygen will cause the mass to ignite.

The reactor blocks are contacted with a fine spray of water at about room temperature in an atmospheric environment. The gaseous effluent from said contact comprises hydrogen and oxygen and burns when subjected to electrical sparking. The volume of gas evolved is dependent on reactor block surface area and the volume of water impinging thereon. Generally a 2.5 square cm surface will react with 0.20 gallons of water per minute.

Although the invention has been described in detail with respect to specific examples, it will be appreciated that various changes and modifications can be made by those skilled in the art within the scope of the invention as expressed in the following claims.

I claim:

1. A material for the generation of hydrogen and oxygen from water which comprises an amalgam of an alkali metal, mercury and aluminum wherein the atomic ratio of alkali metal to mercury is from about 3:1 to about 1:1.5 and the atomic weight ratio of alkali metal to aluminum is from about 1:1 to about 3:1 combined with an alloy of platinum and at least one element selected from the group consisting of germanium, antimony, gallium, thallium, indium, cadmium, bismuth, lead, zinc and tin.

2. The material of claim 1 further characterized in that the alkali metal is sodium or potassium.

3. The material of claim 1 further characterized in that the alloy comprises platinum and at least one metal selected from the group consisting of germanium, antimony, gallium, thallium, indium and cadmium and the alkali metal of the amalgam is sodium.

4. The material of claim 3 further characterized in that the alloy comprises platinum and antimony.

5. The material of claim 3 further characterized in that the alloy comprises platinum and germanium.

6. The material of claim 3 further characterized in that the alloy also contains a metal selected from the group consisting of zirconium, chromium and mixtures thereof.

7. The material of claim 3 further characterized in that the alloy also contains a metal selected from the group consisting of lead, gold and mixtures thereof.

8. The material of claim 3 further comprising copper.

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9. The material of claim 3 further characterized in that the ratio, by weight, of alloy to amalgam is from about 1:1 to about 1:5.

10. The material of claim 9 further characterized in that the ratio, by weight, of alloy to amalgam is about 1:1 to about 1:3.

11. The material of claim 6 further characterized in that the alloy contains from about 0.7% to about 1.1% by weight chromium.

12. The material of claim 3 further characterized in that the each of the metallic components of the alloy present in said material is present in an amount of from about 0.4 to about 28.5 weight percent based upon the weight of alloy and amalgam combined.

13. The material of claim 1 further characterized in that said alloy comprises platinum present in an amount of from about 0.7 to about 1.1% by weight, lead present in an amount of from about 42.9 to about 71.5% by weight, antimony present in an amount of from about 25.5 to about 42.5% by weight, chromium present in an amount of from about 0.7 to about 1.1% by weight, zirconium present in an amount of from about 4.1 to about 6.8% by weight and gold present in an amount of from about 1.1 to about 1.9% by weight.

14. The material of claim 13 further characterized in that said alloy comprises about 0.9 wt.% platinum, about 57.3 wt.% lead, about 34.0 wt.% antimony, about 0.9 wt.% chromium, about 5.4 wt.% zirconium and about 1.5 wt.% gold.

15. A process for the generation of hydrogen and oxygen from water which comprises contacting water with an amalgam of an alkali metal, mercury and aluminum wherein the atomic ratio of alkali metal to mercury is from about 3:1 to about 1:1.5 and the atomic weight ratio of alkali metal to aluminum is from about 1:1 to about 3:1 combined with a platinum-containing alloy.

16. The process of claim 15 further characterized in that the alkali metal is sodium, potassium or mixtures thereof.

17. The process of claim 16 further characterized in that the alloy comprises platinum and at least one metal selected from the group consisting of germanium, antimony, gallium, thallium, indium, cadmium, bismuth, lead, zinc and tin.

18. The process of claim 15 further characterized in that the alloy comprises platinum and at least one metal

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selected from the group consisting of germanium, antimony, gallium, thallium, indium and cadmium and the alkali metal of the amalgam is sodium.

19. The process of claim 18 further characterized in that the alloy comprises platinum and antimony.

20. The process of claim 18 further characterized in that the alloy comprises platinum and germanium.

21. The process of claim 18 further characterized in that the alloy also contains a metal selected from the group consisting of zirconium, chromium and mixtures thereof.

22. The process of claim 18 further characterized in that the alloy also contains a metal selected from the group consisting of lead, gold and mixtures thereof.

23. The process of claim 18 further comprising copper.

24. The process of claim 18 further characterized in that the ratio, by weight, of alloy to amalgam is from about 1:1 to about 1:5.

25. The process of claim 24 further characterized in that the ratio, by weight, of alloy to amalgam is about 1:1 to about 1:3.

26. The process of claim 21 further characterized in that the alloy contains from about 0.7% to about 1.1% by weight chromium.

27. The process of claim 18 further characterized in that each of the metallic components of the alloy present in said material is present in an amount of from about 0.4 to about 28.5 weight percent based upon the weight of alloy and amalgam combined.

28. The process of claim 15 further characterized in that said alloy comprises platinum present in an amount of from about 0.7 to about 1.1% by weight, lead present in an amount of from about 42.9 to about 71.5% by weight, antimony present in an amount of from about 25.5 to about 42.5% by weight, chromium present in an amount of from about 0.7 to about 1.1% by weight, zirconium present in an amount of from about 4.1 to about 6.8% by weight and gold present in an amount of from about 1.1 to about 1.9% by weight.

29. The process of claim 28 further characterized in that said alloy comprises about 0.9 wt.% platinum, about 57.3 wt.% lead, about 34.0 wt.% antimony, about 0.9 wt.% chromium, about 5.4 wt.% zirconium and about 1.5 wt.% gold.

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**United States Patent** [19][11] **4,184,931****Inoue**[45] **Jan. 22, 1980****[54] METHOD OF ELECTROLYTICALLY  
GENERATING HYDROGEN AND OXYGEN  
FOR USE IN A TORCH OR THE LIKE****[75] Inventor: Kiyoshi Inoue, Tokyo, Japan****[73] Assignee: Inoue-Japax Research Incorporated,  
Yokohamashi, Japan****[21] Appl. No.: 884,804****[22] Filed: Mar. 9, 1978****[30] Foreign Application Priority Data**

Mar. 10, 1977 [JP] Japan ..... 52-26319

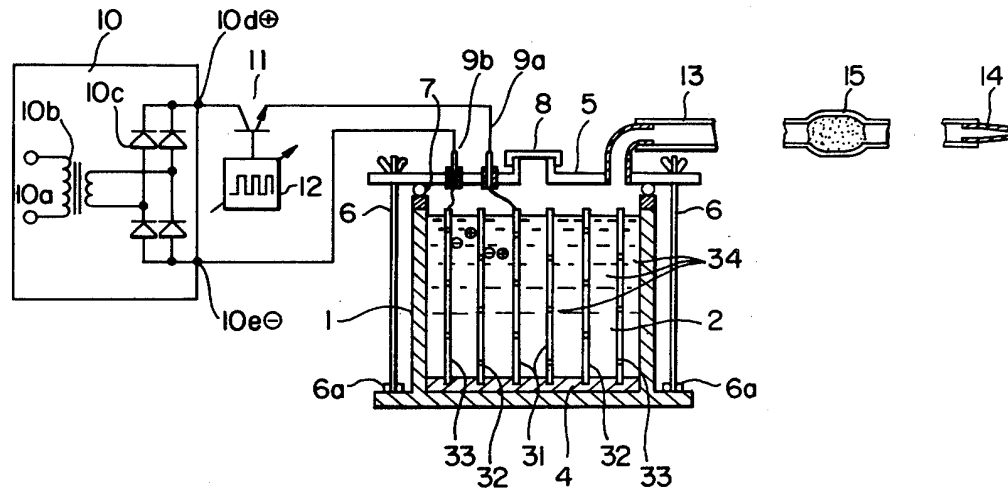
Dec. 28, 1977 [JP] Japan ..... 52-157377

**[51] Int. Cl.<sup>2</sup> ..... C25B 1/04****[52] U.S. Cl. .... 204/129****[58] Field of Search ..... 204/129****[56]****References Cited****U.S. PATENT DOCUMENTS**

3,652,431	3/1972	Reynolds	204/129
3,933,614	1/1976	Bunn	204/129
3,954,592	5/1976	Horvath	204/129
3,980,053	9/1976	Horvath	204/129

*Primary Examiner—R. L. Andrews**Attorney, Agent, or Firm—Karl F. Ross***[57]****ABSTRACT**

Hydrogen/oxygen mixtures for combustion in torches or the like are produced by the pulsed electrolysis of an aqueous medium. The pulse duration is 1 to 500 microseconds.

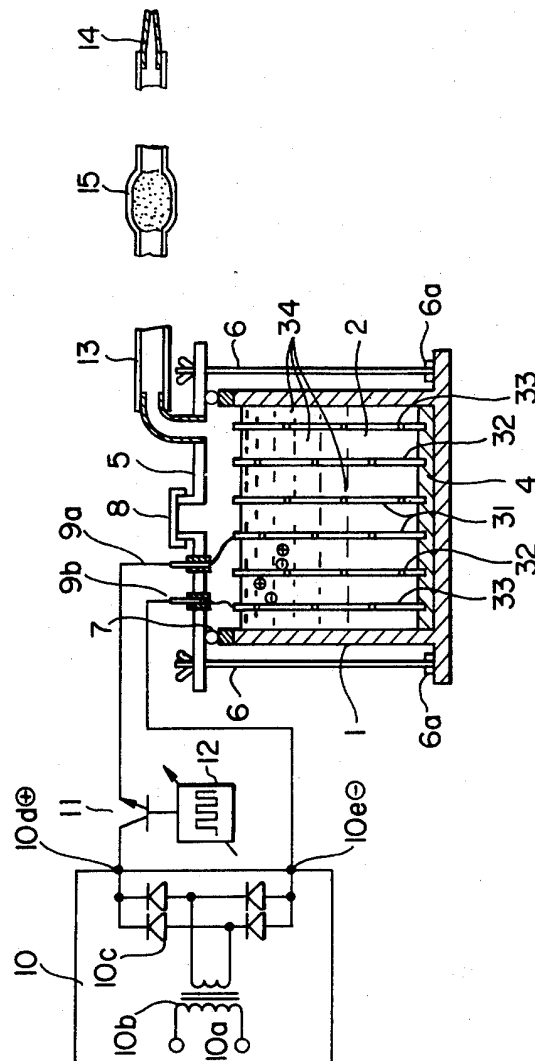
**4 Claims, 1 Drawing Figure**



U.S. Patent

Jan. 22, 1980

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## METHOD OF ELECTROLYTICALLY GENERATING HYDROGEN AND OXYGEN FOR USE IN A TORCH OR THE LIKE

### FIELD OF THE INVENTION

The present invention relates to an improved method of electrolytically generating hydrogen and oxygen gases for a torch or the like.

### BACKGROUND OF THE INVENTION

There has heretofore been known, as described for example in U.S. Pat. No. 3,262,872, the use for a torch or the like of a mixture of hydrogen and oxygen gases generated by electrolytic decomposition of water and ignited to produce a flame for welding, brazing or the like. This technique typically employs a pair of electrodes immersed in electrolytically conductive water and juxtaposed with one another in a tightly closed tank containing the water, the electrodes being energized by a direct-current power supply for passing an electric current therebetween to electrolytically generate hydrogen and oxygen gases. The hydrogen and oxygen gases may be evolved into a space above the surface of the water in the tank to form a mixture thereof which is led through a conduit to a torch or nozzle where it is to be ignited. In order to ensure a stabilized production of the flame from the electrolytically generated gases, it is required or desirable to generate the gases at a sufficient rate and with efficiency, to deliver the gases at a constant amount and under a constant pressure and further to assure that the gases delivered be free from steam, moisture or aqueous condensate (i.e., to be sufficiently dry). To this end, various measures have been proposed including the use of a plurality of electrically conductive cylinders as electrodes concentrically arranged in the water tank for energization by the power supply to produce gases at plural locations as well as the floating of a hydrocarbon in an attempt to control the aqueous evaporation, all with only limited success.

### OBJECTS OF THE INVENTION

It is therefore an object of the invention to provide an improved electrolytic hydrogen and oxygen production method whereby the disadvantages which have been encountered in the prior art are overcome or alleviated.

A specific object of the invention is to provide an improved method of the type described which enables continuous generation of a greater amount of hydrogen and oxygen gases and is capable of reducing the steam, moisture or aqueous condensate evolved during the electrolytic decomposition process of water.

### SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided a method of electrolytically generating hydrogen and oxygen for a torch or the like, in which an electric current in the form of pulses is applied between at least a pair of electrodes at least partly immersed in electrolytically-conductive water and juxtaposed with one another in a tightly closed tank containing the water. The pulsed electric current, in accordance with a more specific aspect of the invention, has a pulse duration or "on" time not greater than 500 microseconds, preferably not greater than 50 microseconds and practically not less than 1 or 5 microseconds. The pulse "off" time or interval between adjacent pulses should prefera-

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bly be not less than two times but not greater than thirty times longer than the pulse "on" time or duration.

An apparatus for carrying out the method according to the invention comprises a tightly closed tank for receiving electrolytic water, at least a pair of electrodes at least partly immersed in the electrolytic water and juxtaposed with one another and a power supply connected to said electrodes for passing an electrolyzing current therebetween in the form of pulses with the pulse duration or "on" time, preferably in the range between 5 and 500 microseconds. Preferably, said power supply is adapted to provide time-spaced, discrete electrical pulses with "on" time and "off" time selectively adjustable and may comprise a direct-current source, an electronic switching unit switch-controllable by a control pulser or oscillator with an adjustable control pulse "on" time and "off" time or frequency for alternately connecting and disconnecting said direct-current source across said electrodes so as to pass a pulsed electrolyzing current therebetween with the adjusted pulse duration and interval. The power supply may be alternated, though with less control or adjusting flexibility, by a high-frequency alternating-current source having a rectifier coupled thereto and across the electrodes such that a pulsating current is applied across the electrolyzing electrodes. In this case, the alternating current source preferably has an output frequency in the range between 1 to 500 kHz or the range between 200 Hz to 20 kHz so that the pulsating current for electrolysis has a pulse duration in the range between 1 to 500 microseconds. Alternatively, the power supply may use a capacitor connected across the electrodes in parallel to a direct-current source with a switching unit possibly interposed and circuit parameters being adapted to provide a pulsating electrolyzing current of each pulse duration preferably in the range specified. Such pulsing power supply systems and various modifications thereof are well known and description of further details thereof here are unnecessary.

### BRIEF DESCRIPTION OF THE DRAWING

In the drawing, the sole FIGURE is a diagrammatic view illustrating an electrolytic hydrogen and oxygen generator shown in section and partly broken away and including an exemplary power supply assembly shown in a schematic circuit diagram for carrying out the improved method according to the invention.

### SPECIFIC DESCRIPTION

The generator illustrated includes a tank 1 containing an aqueous electrolyte or electrolytically-conductive water 2 which is water plus an electrolyte that may, for example, be potassium hydroxide (KOH). In the tank 1, there are provided a plurality of cylindrical electrodes here shown as three cylinders 31, 32 and 33 arranged concentrically and of successively increased diameters. Each of the cylindrical electrodes 31, 32 and 33 fixedly mounted upon an electrically nonconductive base 4 at the bottom of the tank 1 is shown uniformly provided with perforations 34 to allow free passage of the electrolytic water 2 therethrough. A greater number of electrodes may, of course, be provided according to the volume of the tank 1 utilized.

The tank 1 is tightly sealed by a cover 5 which is clamped by means of a plurality of bolts 6 against a sealing gasket 7 interposed between the cover 5 and the tank 1. The bolts 6 are held upright upon the base of the tank 1 and clamped thereon with nuts 6a. A cap 8 is

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provided on the cover 5 for supply and replenishment of the electrolytic water into the tank 1.

The innermost electrode 31 and the outermost electrode 33 are electrically connected to electrical terminals 9a and 9b, respectively. The power supply assembly illustrated includes a direct-current source 10 here comprising a commercial alternating-current input 10a, a transformer 10b and a rectifier 10c for providing a direct-current potential at the outputs 10d, 10e. The negative output terminal 10e of the DC source 10 are shown connected directly to the electrode terminal 9b while the positive output terminal 10d is shown connected to the electrode terminal 9a via a switch 11 which is here shown comprising a transistor. The switch 11 is on/off controlled by an oscillator or control pulser 12 (e.g. a multivibrator of conventional design or equivalent thereof) of adjustable "on" time, "off" time and frequency of output control pulses to apply between the terminals 9a and 9b and hence between the electrodes 31 and 33 a succession of pulses of preset "on" time, "off" time and frequency, with the pulse "on" time or duration preferably in the range not greater than 500 microseconds, more preferably not greater than 50 microseconds and practically not less than 1 or 5 microseconds, and the pulse "off" time or interval preferably not less than two times but not greater than thirty times longer than the pulse "on" time or duration as mentioned previously.

As a consequence, an electrolyzing current is passed between the electrodes 31 and 32 and between the electrodes 32 and 33 with hydrogen evolving from the inner surfaces of the electrodes 32 and 33 and oxygen from the outer surfaces of the electrodes 31 and 32. The mixture of hydrogen and oxygen gases collected in the space in the tank 1 above the water surface is led with a conduit 13 to a torch 14, at which it is ignited, through a flash-back arrestor 15. The latter may contain metallic particles, mesh, fibers, wools or porous bodies to additionally serve as a filter.

The pulsed electrolysis of water according to the invention has been found to be extremely advantageous in comparison with continuous electrolysis as is the practice of the prior art. It permits the current density to be greatly enhanced leading to a larger amount of both hydrogen and oxygen gases being generated. This appears to result partly from the cooling of water effected during pulse intervals. Even more significant is the fact that a drier gas mixture with less moisture generated is obtained which enables a stabilized flame of an elevated temperature to result at the torch or nozzle 14 continuously without the failure of ignition.

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## EXAMPLE

Following the conventional practice, a stationary direct-current of 1 ampere was passed through an aqueous solution containing 20% by weight potassium hydroxide with the result of the rate of gas production of 55 cc/min and the gases containing 15%. In comparison, when a pulsed electrolyzing current of pulse "on" time and "off" time both of 20 microseconds was employed in accordance with the invention, the gases were produced at a rate of 68 cc/min and contained less than 3% moisture. The resulting flame had an increased stability and higher temperature.

The pulsed electrolysis according to the invention is especially remarkable in its effect when the pulse "on" time or duration is in the range not greater than 500 microseconds, preferably not greater than 50 microseconds and practically not less than 1 or 5 microseconds and the pulse "off" time or interval as mentioned earlier.

The pulse duration and possibly also the interval may be adjusted in observing the stability of the flame created at the torch. As mentioned earlier, therefore, it is desirable to design the pulser adjustable as to the pulse duration and interval or frequency in sufficient widths.

I claim:

1. A method of operating a torch, comprising the steps of:

electrolytically generating hydrogen and oxygen by passing an electric current in the form of pulses of a duration not greater than 50 microseconds between at least a pair of electrodes at least partly immersed in electrolytically conductive water and juxtaposed with one another in a tightly closed tank containing the water;

feeding the hydrogen and oxygen thus produced to a torch nozzle to form a mixture; and igniting said mixture at said nozzle.

2. The method according to claim 1, in which the pulse interval between adjacent pulses is not less than two times but not greater than thirty times longer than the pulse duration.

3. The method according to claim 1 in which said electrodes are constituted by a plurality of electrically conductive cylinders concentrically arranged in said tank and of successively increased diameters, said electric current in the form of pulses being applied between the innermost electrode and the outermost electrode with one or more intermediate electrodes forming bipolar electrodes.

4. The method according to claim 1, in which the innermost electrode is poled anodic and the outermost electrode is poled cathodic.

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# United States Patent [19]

## Duckworth

[11] **4,200,062**  
[45] **Apr. 29, 1980**

### [54] SAFETY SWITCH FOR HYDROGEN GENERATOR SYSTEM

[76] Inventor: **Charles E. Duckworth**, 1421 SE. 10th St., Deerfield Beach, Fla. 33441

[21] Appl. No.: **923,863**

[22] Filed: **Jul. 12, 1978**

[51] Int. Cl.<sup>2</sup> ..... **F02B 43/08**

[52] U.S. Cl. .... **123/1 A; 123/3; 123/119 E; 123/DIG. 12**

[58] Field of Search ..... **123/DIG. 12, 1 A, 3, 123/119 E**

### [56] References Cited

#### U.S. PATENT DOCUMENTS

3,648,668	3/1972	Pacheco	123/3
4,023,545	5/1977	Mosher et al.	123/3
4,031,865	6/1977	Dufour	123/1 A
4,141,326	2/1979	Wolber	123/DIG. 12

*Primary Examiner*—Charles J. Myhre

*Assistant Examiner*—Craig R. Feinberg

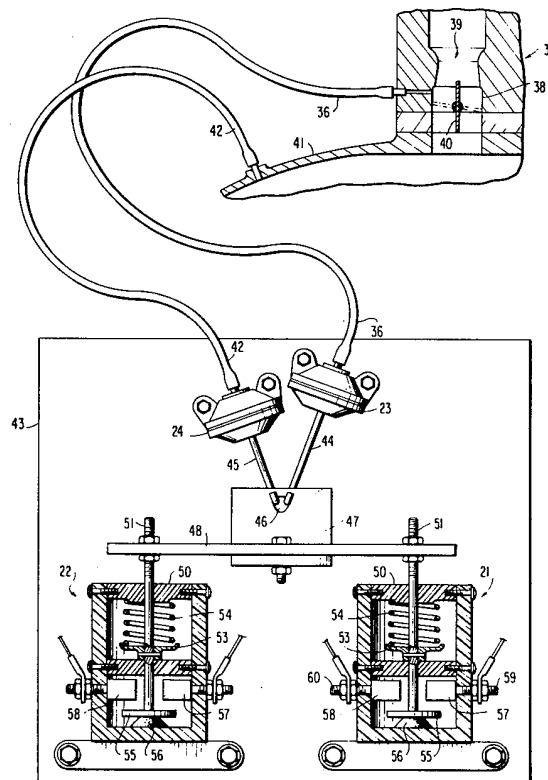
*Attorney, Agent, or Firm*—C. Lamont Whitham

### [57] ABSTRACT

A safety cutoff switch for a hydrogen gas generator system is disclosed. The hydrogen gas generator system is of the type for use with automotive internal combustion engines wherein combustible hydrogen gas generated by the system is co-mingled with exhaust gases from the internal combustion engine and fed into the

intake manifold. The hydrogen gas generator system includes a group or groups of hydrogen gas fuel cells which are provided with electrical current generated by alternators driven by the engine or the automotive drive train. The current from the alternators is supplied through the safety cutoff switch and individual, manually operable switches to each fuel cell. The safety cutoff switch comprises a solenoid structure having a spring biased armature carrying an electrical contactor for making an electrical circuit between two electrical contact posts. Movement of the armature makes or breaks electrical contact between the two electrical contact posts, and the spring bias of the armature is such that the electrical circuit between the two electrical contact posts is normally an open circuit. A pair of vacuum actuators are provided to act against the spring bias of the armature and cause the electrical contactor to make the circuit between the two electrical contact posts. One of the vacuum actuators is connected by a hose to the venturi of the engine carburetor, while the other vacuum actuator is connected by a hose to the intake manifold. Thus, when the engine is running, one or the other of the vacuum actuators operates to actuate the safety cutoff switch, but in the event that the engine stops running, the spring bias of the switch opens the electrical circuit supplying current to the fuel cells.

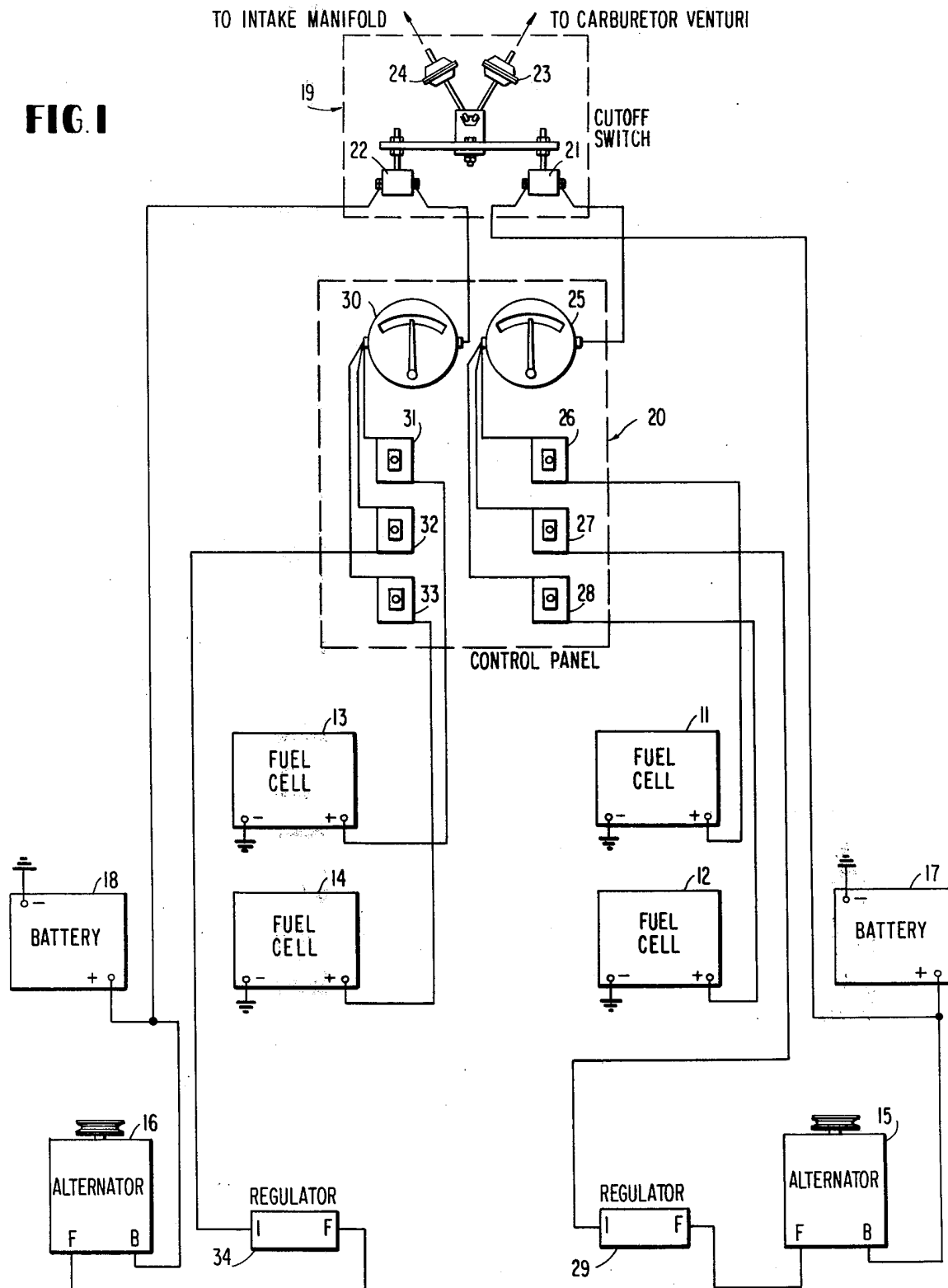
**5 Claims, 2 Drawing Figures**



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Sheet 1 of 2

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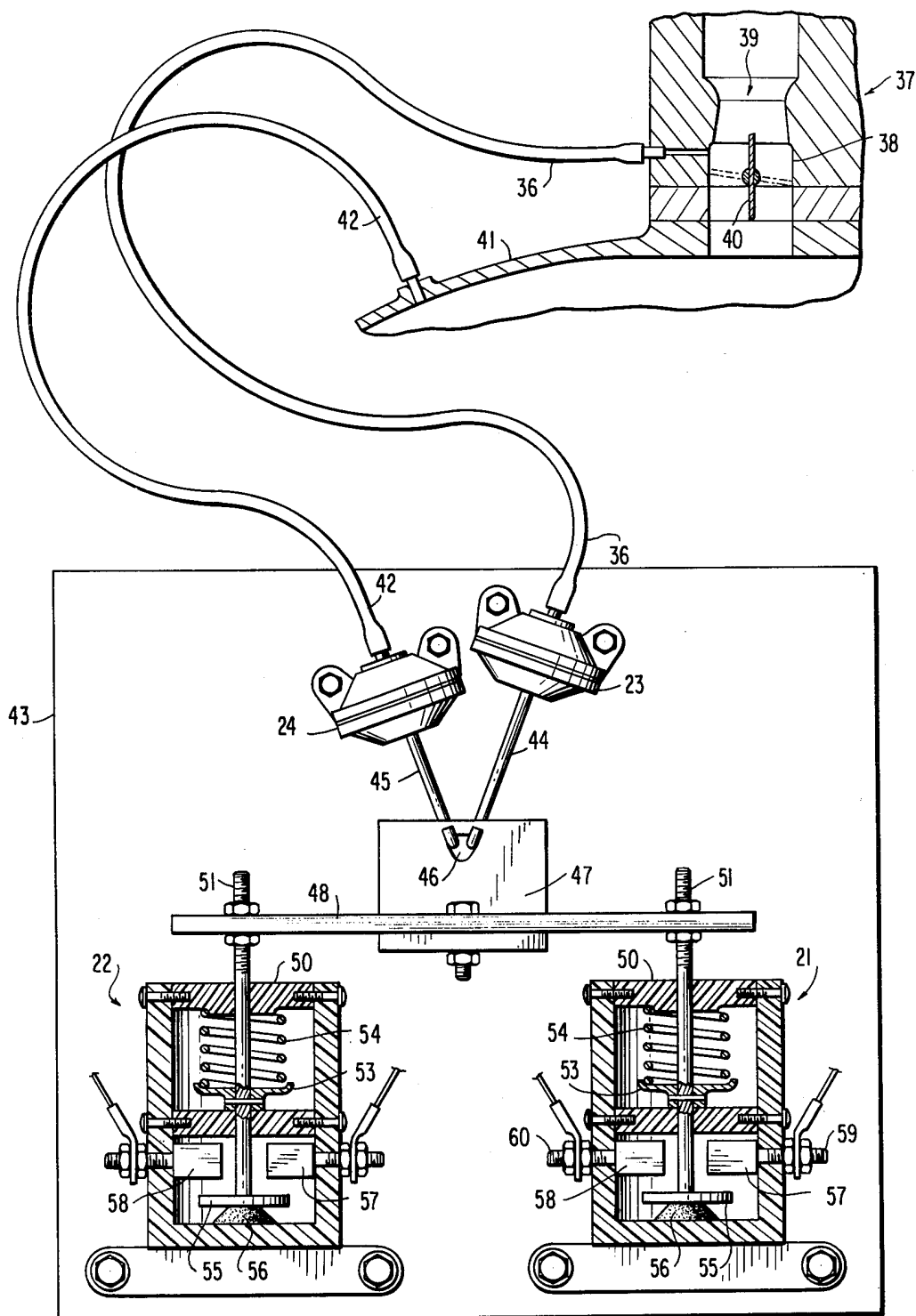
**FIG. 1**

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FIG. 2



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## SAFETY SWITCH FOR HYDROGEN GENERATOR SYSTEM

### BACKGROUND OF THE INVENTION

The present invention generally relates to hydrogen gas generator systems for use as supplemental fuel sources for automotive internal combustion engines and, more particularly, to a safety cutoff switch for stopping the production of hydrogen by the fuel cells when the engine stops running.

The generation of hydrogen as a supplemental fuel for internal combustion engines has been well known for many years. For example, U.S. Pat. No. 1,632,285 to Georgi discloses a gas generator wherein a combustible gas is formed from a hydrogenator and co-mingled with exhaust gases from an internal combustion engine and fed into the carburetor inlet manifold. Suitable valves prevent a back pressure flow from the engine, and means are provided for the use of a rheostat and ammeter to control the supply of current to the electrodes of the hydrogenator. More recently, U.S. Pat. No. 4,023,545 to Mosher et al. discloses an energy means for internal combustion engines utilizing a hydrogenator as an auxiliary system to enhance the combustion of the fuels used within the engine. Suitable valves are arranged within the manifold section for supplying the hydrogen and oxygen gases.

The use of hydrogen as an auxiliary fuel has been attractive for many years and is now the subject of considerable investigation because of the impending shortages of hydrocarbon fuels. In its simplest form, a hydrogen generating fuel cell is simply an electrolytic cell which produces hydrogen and oxygen by the electrolysis of water. All that is needed is a source of electrical current to supply the electrolytic cell, and this can be provided by means of an alternator driven by the engine or the drive train of the automotive vehicle. There are, however, certain dangers in the use of hydrogen as a fuel due to its being so highly combustible. Because of this, it is preferable to consume the hydrogen gas as a fuel as it is generated rather than accumulate and store it.

In my earlier U.S. Pat. No. 4,068,628, I disclosed a multi-cylinder, gasoline burning, internal combustion engine which is converted by modification of the intake and exhaust manifolds to an engine having designated exhaust burning cylinders which burn the exhaust gases that are expelled from the gasoline burning cylinders. To this system, I have added a hydrogen generating system which supplies the highly combustible hydrogen gas to the intake manifold for the designated exhaust burning cylinders. While this system works quite well, it is necessary to consider the safety of the system should it be in general public use. For example, in the event of an accident or for some reason the engine stops running so that the hydrogen generated is not consumed in the normal operation and functioning of the automobile, it is necessary to provide some means by which the production of the hydrogen is stopped when the engine stops running.

The above-referenced patent to Mosher et al. also recognizes that, as a prerequisite to the generation of hydrogen for supply to the intake manifold, the engine must be operating. U.S. Pat. No. 3,710,770 to Newkirk et al. discloses a pressure switch which is used as a safety switch to shut off the supply of hydrogen to the engine in the event that the engine does not start as it

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should. Neither Mosher et al. or Newkirk et al., however, provide a fail-safe system which will quickly and positively cause the generation of hydrogen to cease in the event that the engine stops running.

### SUMMARY OF THE INVENTION

It is therefore an object of my invention to provide a safety cutoff switch for a hydrogen gas generator system of the type used to supply hydrogen gas as a supplemental fuel to automotive internal combustion engines and, more particularly, to such a safety cutoff switch which is fail-safe, assuring the instantaneous and positive cessation of hydrogen production when the engine stops running.

My safety cutoff switch is particularly useful in a hydrogen gas generating system wherein one or more groups of hydrogen gas fuel cells are provided with electrical current generated by alternators driven by the engine or the automotive vehicle drive train. The current from the alternators is supplied through the safety cutoff switch and individual, manually operable switches to each fuel cell. A separate ammeter may be provided for each group of fuel cells, and the ammeters and manually operable switches may be conveniently located on the instrument panel of the automotive vehicle.

According to the present invention, the safety cutoff switch comprises a solenoid structure having a spring biased armature which carries an electrical contactor. Linear movement of the armature causes the electrical contactor to contact or move away from two electrical contact posts, thereby making or breaking an electrical circuit connected to the two electrical contact posts. The spring bias on the armature is such as to make the armature move the electrical contactor out of contact with the two electrical contact posts so that the electrical circuit connected thereto is normally opened. A pair of vacuum actuators are mechanically connected to the armature of the switch and act against the spring bias of the armature to cause the electrical contactor to come into contact with the two electrical contact posts and make the electrical circuit connected thereto. One of the vacuum actuators is connected by a hose to the venturi of the engine carburetor, while the other vacuum actuator is connected by a hose to the intake manifold. As is well known, when the throttle of the carburetor is closed, the intake manifold of the engine is at a low pressure or high vacuum, whereas the venturi of the carburetor is at a high pressure or low vacuum. Thus, when the engine is running and the throttle is closed, the vacuum actuator connected to the intake manifold operates to move the switch armature against the spring bias so as to bring the electrical contactor into contact with the two electrical posts of the switch. On the other hand, when the throttle valve is open, the intake manifold is at a high pressure or low vacuum, whereas the carburetor venturi is at low pressure or high vacuum. Thus, when the engine is running and the throttle valve is in the open position, the vacuum actuator connected to the carburetor venturi acts against the spring bias of the switch armature to bring the electrical contactor into contact with the two electrical posts of the switch. Thus, when the engine is running, one or the other of the vacuum actuators operates to actuate the safety cutoff switch so as to make the electrical circuit which is connected to the two electrical posts, but in the event that the engine stops running, the spring bias of

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the switch armature opens the electrical circuit and stops the supply of current to the fuel cells.

### BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, aspects and advantages of the invention will be better understood from the following detailed description of a preferred embodiment with reference to the accompanying drawings, in which:

FIG. 1 is a schematic diagram showing a hydrogen generating system using the safety cutoff switch according to my invention; and

FIG. 2 is a detailed view, partially in cross section, of a preferred embodiment of the safety cutoff switch according to the invention.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings and, more particularly, to FIG. 1, there is shown a hydrogen gas generator system comprising two groups of fuel cells 11, 12 and 13, 14. The fuel cells in each group are electrically connected in parallel and supplied with current generated by respective alternators 15 and 16. The alternators 15 and 16 can be driven by a crankshaft pulley provided on the engine, or, in one actual embodiment of the system, the alternators 15 and 16 are driven by a pulley attached to the differential in the drive train of the automotive vehicle. The alternators 15 and 16 are energized by batteries 17 and 18, respectively, and supply current through the cutoff switch 19 and the control panel 20 to each of the respective groups of fuel cells 11, 12 and 13, 14. The cutoff switch 19 will be described in more detail with reference to FIG. 2, but generally comprises two solenoid switch structures 21 and 22 operated by a pair of vacuum actuators 23 and 24 acting through a control link and actuator bar assembly. One solenoid switch structure 21 or 22 is provided for each group of fuel cells 11, 12 or 13, 14. The vacuum actuator 23 is connected by a hose to the carburetor venturi, while the vacuum actuator 24 is connected by a hose to the intake manifold of the engine.

The control panel 20 comprises an ammeter and a bank of manually operable switches for each group of fuel cells. Thus, current generated by alternator 15 for fuel cells 11 and 12 is supplied via the solenoid switch structure 21 to an ammeter 25 and thence in parallel to switches 26 and 28 which supply current to fuel cells 11 and 12, respectively. In addition, a switch 27 is connected between the ammeter 25 and a voltage regulator 29 which controls the current returned to the field winding of the alternator 15. Thus, by means of manually operable switches 26 and 28, it is possible for the operator to connect or disconnect the supply of current to the fuel cells 11 and 12, and, by means of switch 27, it is possible for the operator to turn off alternator 15. However, it will be observed that by turning off alternator 15, current will still be supplied to fuel cells 11 and 12 by battery 17.

Similar connections are made for the second group of fuel cells 13 and 14. Specifically, battery 18 energizes alternator 16 which supplies current through the solenoid switch structure 22 to ammeter 30. Switches 31, 32 and 33 are connected in parallel to ammeter 30, switches 31 and 33 being connected to supply fuel cells 13 and 14, while switch 32 is connected to supply current via voltage regulator 34 to alternator 16. Fuel cells 13 and 14 can be turned on or off by means of manually operable switches 31 and 33, and alternator 16 can be

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turned on or off by means of manually operable switch 32. But, again, when the alternator 16 is turned off by means of manually operable switch 32, current is still supplied to fuel cells 13 and 14 by battery 18.

It will be appreciated that if only one group of fuel cells is used, then only one alternator, battery, solenoid switch structure, ammeter and group of manually operable switches are required. Conversely, each additional group of fuel cells is preferably provided with its own alternator, battery, solenoid switch structure, ammeter and group of manually operable switches.

While the control panel 20 provides manual switch control of each one of the fuel cells and each one of the alternators, the purpose of this invention is provide a safety cutoff switch which will ensure that current to all of the fuel cells will be interrupted when the engine is not running or ceases to run as may happen, for example, in an accident. Especially under the emergency conditions that may be presented in the event of an accident, it is imperative that there be a cessation of the generation of hydrogen which is highly flammable. The safety cutoff switch 19 provides a fail-safe control, ensuring that current is cut off to each of the fuel cells when the engine is not running.

Reference is now made to FIG. 2 which shows in more detail the structure of the safety cutoff switch according to the invention. The vacuum actuator 23 is connected by a hose 36 to the venturi area of a carburetor 37 for the automobile engine. The carburetor 37 is shown only very schematically but comprises a barrel 38 having a venturi area 39 and a throttle valve 40. Carburetor 37 is mounted on the intake manifold 41 of the engine. The vacuum actuator 24 is connected by hose 42 to the intake manifold 41. The throttle valve 40 is shown in the full open position in the figure, and, as is well known, this results in a low pressure or a high vacuum condition in the venturi area of the carburetor 37 and a high pressure or low vacuum condition in the intake manifold 41. As a result, the vacuum actuator 23 is actuated, but the vacuum actuator 24 is not. On the other hand, when the throttle valve 40 is in the full closed position, there results a high pressure or low vacuum condition in the venturi area 39 of the carburetor 37 and a low pressure or high vacuum condition in the intake manifold 41. Under this condition, the vacuum actuator 24 is actuated, but the vacuum actuator 23 is not. The important point to be understood is that one or the other of the vacuum actuators 23 or 24 will be actuated when the engine is running; however, when the engine ceases to run, neither of the vacuum actuators 23 or 24 are actuated.

The vacuum actuators 23 and 24 are suitably mounted to a fixed plate 43, but may just as easily be mounted to the fire wall of the engine compartment. The actuators 23 and 24 operate through the link and bar assembly to control the solenoid switch structures 21 and 22. More specifically, vacuum actuator 23 is provided with a hooked actuator rod 44, and vacuum actuator 24 is provided with a hooked actuator rod 45. Both of the hooked actuator rods 44 and 45 engage a slot 46 in plate 47. The plate 47 is attached to a bar 48 made of an electrical insulating material, such as a suitable plastic. One end of the bar 48 is connected to the armature of switch solenoid structure 21, while the other end of bar 48 is connected to the armature of solenoid switch structure 22.

The solenoid switch structures 21 and 22 are identical, and, therefore, the description of these structures



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will be made only with reference to solenoid switch structure 21, it being understood that the same description applies to solenoid switch structure 22. The solenoid switch structure 21 has an outer shell case 49 made of an electrical insulating material, such as a suitable plastic. This shell case 49 is fixedly attached to the plate 43 or directly to the fire wall of the engine compartment. The top of the case 49 is closed with a cover plate 50 having an aperture therein through which the armature shaft 51 passes to the attachment at the end of bar 48. A second plate 52 similar to the cover plate 50 is positioned within the case 49 and also has an aperture through which the shaft 51 of the armature passes. The plates 50 and 52 are preferably made of a plastic material and act as bearings for the axial movement of the armature shaft 51. The armature shaft 51 is provided with a spring retainer plate 53 which is fixedly attached thereto. A coil spring 54 is positioned between the spring retainer 53 and the under surface of the top cover plate 50. The spring 54 biases the armature shaft 51 for movement in a downward direction as viewed in the figure. At the lowermost end of the armature shaft 51, there is fixedly attached an electrical contactor 55. The electrical contactor may be made of brass or other suitable good electrical conductor. Just below the electrical contactor 55 is a resilient bumper 56 made of rubber or other elastomeric material. The purpose of the bumper 56 is to arrest the downward movement of the armature shaft 51 and contactor 55 and provide quietness of operation of the switch. Two electrical contact posts 57 and 58 are positioned within the case 49 on opposite sides thereof and above the electrical contactor 55. Electrical post 57 is provided with a threaded electrical terminal 59 which projects through the case 49 for connection to ammeter 25 on the control panel 20. Electrical contact post 58 is also provided with an electrical terminal 60 which projects through the case 49 for connection to the positive terminal of battery 17. Both the electrical contact posts 57 and 58 and their respective terminals 59 and 60 may be made of brass or other suitable good electrical conductor.

In operation, when the engine is not running, the electrical armature shaft 51 is in its downward-most position so that the electrical contactor 55 rests on the bumper 56 and out of contact with the electrical posts 57 and 58. However, once the engine is running, one or the other of the vacuum actuators 23 or 24 will be actuated so that their respective actuator shafts 44 or 45 will exert an upward force on the plate 47, thereby pulling armature shaft 51 upwardly against the bias spring 54 so that the electrical contactor 55 will contact the electrical posts 57 and 58, thereby making the circuit between the positive terminal of battery 17 and the ammeter 25. Should the engine stop running, then neither of the vacuum actuators 23 or 24 will be actuated, with the result that no upwardly directed force will be applied to the plate 47 so that the bias spring 54 will cause the armature shaft 51 to move downwardly, thereby breaking the circuit between the positive terminal of battery 17 and the ammeter 25.

While a preferred embodiment of the invention has been described, it will be understood by those skilled in the art that the various modifications and arrangements can be made without departing from the scope of the invention. The system as described provides electrical current for the independent operation of multiple groups of hydrogen fuel cells. It is preferred to have this electrical system independent of the vehicle electrical system, but, if desired, the two electrical systems could be connected in parallel to provide a unified electrical system for the vehicle. This could be helpful in case of

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failure of an alternator or a battery. For example, if the battery normally used for the vehicle starter and ignition system became completely discharged and the starter therefore could not start the vehicle, a switch could be provided between the vehicle system battery and one of the hydrogen fuel cell auxiliary batteries (17 or 18) which would enable the starter to function. It will be appreciated, however, that whatever form the electrical system takes, the invention provides a fail-safe safety cutoff switch which assures that the generation of hydrogen by the fuel cells will stop immediately upon the cessation of the running of the engine.

What is claimed is:

1. A safety cutoff switch for use in a hydrogen generating system supplying hydrogen gas as a supplemental fuel to an internal combustion engine, said hydrogen generating system comprising at least one group of fuel cells connected through said safety cutoff switch to a source of electrical current and said internal combustion engine having an intake manifold and a carburetor comprising a venturi and a throttle valve, said carburetor being attached to said intake manifold for supplying a fuel and air mixture to said engine, said safety cutoff switch comprising:

a first vacuum actuator means connected by a hose to said carburetor venturi;

a second vacuum actuator means connected by a hose to said intake manifold; and

switch means mechanically connected to both of said first and second vacuum actuators for actuation thereby to make an electrical connection between said group of fuel cells and said source of electrical current when said engine is running, said switch means breaking said electrical connection in the absence of actuation by both of said first and second vacuum actuator means.

2. A safety cutoff switch as recited in claim 1 wherein said hydrogen generating system comprises a plurality of groups of fuel cells, each group being connected through said safety cutoff switch to said source of electrical current, said safety cutoff switch having a plurality of switch means, one for each group of fuel cells, each of said switch means being mechanically connected in common to both of said first and second vacuum actuators.

3. A safety cutoff switch as recited in claim 1 wherein said switch means comprises spring bias means for breaking said electrical connection in the absence of actuation by both of said first and second vacuum actuator means.

4. A safety cutoff switch as recited in claim 1 wherein said switch means comprises:

an armature shaft mechanically connected to, but electrically insulated from, said first and second vacuum actuator means for movement thereby;

an electrical contactor fixedly attached to said armature shaft;

first and second electrical contact posts positioned for mating contact with said electrical contactor upon movement of said armature shaft by one or the other of said first and second vacuum actuators, said first and second electrical contact posts being electrically connected to said group of fuel cells and to said source of current, respectively; and

spring bias means acting on said armature shaft in a manner to urge said electrical contactor to move out of contact with said first and second electrical contact posts.

5. A safety cutoff switch as recited in claim 4 wherein said armature shaft moves linearly.

\* \* \* \* \*

**United States Patent** [19]

[11]

**4,207,095****Anderson**

[45]

**Jun. 10, 1980**

[54] **MATERIAL AND METHOD FOR  
OBTAINING HYDROGEN BY  
DISSOCIATION OF WATER**

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[73] Assignee: **Horizon Manufacturing Corporation,  
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[21] Appl. No.: **902,705**

[22] Filed: **May 4, 1978**

[51] Int. Cl.<sup>2</sup> ..... **C01B 1/08**

[52] U.S. Cl. .... **75/134 N; 75/169;  
423/657**

[58] Field of Search ..... **75/169, 134 N; 423/657**

[56] **References Cited**

**U.S. PATENT DOCUMENTS**

2,837,408	6/1958	Sakowski	23/184
2,991,176	7/1961	Clancy	75/169
3,181,848	5/1965	Miller	266/34

3,313,598	4/1967	Glackstein	23/211
3,343,948	9/1967	Raclet	75/138
3,490,871	1/1970	Miller et al.	23/210
3,540,854	11/1970	Brooke, Jr. et al.	23/282
3,833,357	9/1974	Bianchi et al.	75/121
3,985,866	10/1976	Oda et al.	423/657

**FOREIGN PATENT DOCUMENTS**

7100847 3/1972 France ..... 423/657

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[57]

**ABSTRACT**

A material and method of use thereof is disclosed which produces hydrogen by decomposition of water. The material is an amalgam of an alkali metal, mercury and aluminum and hydrogen is produced by contacting water therewith.

**4 Claims, No Drawings**

4,207,095

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# MATERIAL AND METHOD FOR OBTAINING HYDROGEN BY DISSOCIATION OF WATER

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates to a material for and method of effecting the decomposition/dissociation of water to form hydrogen. The water is reacted with an amalgam of sodium, aluminum and mercury to form hydrogen and a metallic hydroxide believed to be  $\text{Na}_3\text{Al}(\text{OH})_6$ .

### 2. Description of the Prior Art

It is well known that alkali metals react with water to form hydrogen and the stable alkali hydroxide. The foregoing reaction is rapid, the heat generated intense and the hydrogen formed generally ignites with explosive force. The result is an unsatisfactory and dangerous method of generating hydrogen. Moreover, the resulting alkali metal hydroxide is very stable and regeneration to form the alkali metal is not practical from an economic standpoint.

A simple and facile method of producing hydrogen without spontaneous combustion of the resultant evolved hydrogen where an alkali metal is used has not heretofore been developed.

## SUMMARY OF THE INVENTION

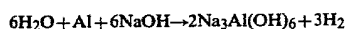
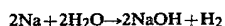
In its broadest aspect, the material found as suitable for generation of hydrogen from water without spontaneous combustion of the resultant evolved hydrogen comprises an amalgam of (1) an alkali metal such as lithium, sodium, potassium, cesium or combinations thereof, (2) aluminum and (3) mercury.

The particle size of the sodium and aluminum is such as to facilitate formation of an amalgam. The amalgam has been prepared utilizing sodium of about  $\frac{1}{4}$  inch diameter and aluminum within the range of about 10 to about 100 mesh. The particle size of either the alkali metal or the aluminum is not critical since the foregoing metals and mercury readily intermix. The smaller the particle size, of course, the more rapid the mixing.

The atomic weight ratio of alkali metal to mercury is from about 1:100 to about 100:1 and the atomic weight ratio of alkali metal to aluminum is from about 1:100 to about 100:1. Preferably the atomic weight ratio of alkali metal to mercury is from about 3:1 to about 1:1.5 and the atomic weight ratio of alkali metal to aluminum is from about 1:1 to about 3:1.

Although not wishing to be bound by the following explanation, it is believed that the water reacts with the alkali metal, e.g., sodium, and the aluminum liberating hydrogen to form  $\text{Na}_3\text{Al}(\text{OH})_6$ . The reaction of the water with the amalgam is substantially different from the reaction of the alkali metal component of the amalgam with water. The heat generated by reaction of equivalent amounts of alkali metal in the form of the amalgam is substantially less than where the alkali metal alone is reacted with water. Accordingly, spontaneous combustion of the hydrogen in an oxidizing environment as well as the formation of a highly stable sodium product is avoided where the amalgam of the invention is employed in place of the alkali metal alone.

The process may be depicted as follows:



The amalgam of sodium, aluminum and mercury is prepared utilizing any known procedure for amalgamation with the added important proviso that an inert

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atmosphere be maintained during amalgamation. Amalgamation may be facilitated by utilization of an elevated temperature preferably around  $200^\circ \text{C} \pm 10^\circ \text{C}$ . The amalgam is preferably maintained at this elevated temperature for about 10 minutes where 100 grams are being processed and the time is extended about a minute for each additional 100 gram aliquot.

The resulting amalgam is cooled, generally to room temperature, utilizing an inert atmosphere. For this purpose, either helium or nitrogen are satisfactory. Cooling is preferably effected in a dessicator to insure that no water contacts the amalgam.

Upon cooling, the amalgam solidifies and may be contacted with water by submersion, by spraying the water thereupon, by impinging water in the form of steam thereon or in any other manner. Contact of water at a temperature above  $0^\circ \text{C}$ . produces evolution of hydrogen.

Examples of suitable amalgams are as follows:

Aluminum 37.7 weight per cent, sodium 32.1 weight per cent and mercury 30.2 weight per cent.

Aluminum 22.9 weight per cent, sodium 18.4 weight per cent, mercury 58.7 weight per cent.

Aluminum 19.4 weight per cent, sodium 31.1 weight per cent, mercury 49.5 weight per cent.

## EXAMPLE

### Preparation of Amalgam

35.144 parts by weight of sodium, 13.749 parts by weight of aluminum and 51.107 parts by weight of mercury are formed into an amalgam in an inert atmosphere of nitrogen at an elevated temperature of  $200^\circ \text{C}$ . in a graphite crucible.

The resulting amalgam is cooled to room temperature in a dessicator in an inert nitrogen atmosphere. Thereafter, the amalgam is formed which is a solid but which will liquefy upon agitation.

It is important to note that the amalgam should be prepared in an inert gas atmosphere to prevent premature hydroxide formation.

### Use of Amalgam

The amalgam is placed in a suitable container with one surface thereof exposed. Water is sprayed upon the exposed surface or alternatively the exposed surface may be covered entirely with a layer of water. It is necessary that the amalgam be placed within a container because in the course of contact of the amalgam with water the heat generated during the course of hydrogen generation transforms the amalgam to liquid form. The amalgam regardless of how it is contacted with water will not cause an explosion.

I claim:

1. A material for the generation of hydrogen from water which comprises an amalgam of an alkali metal, mercury and aluminum wherein the atomic weight ratio of alkali metal to mercury is from about 3:1 to about 1:1.5 and the atomic weight ratio of alkali metal to aluminum is from about 1:1 to about 3:1.

2. The amalgam of claim 1 further characterized in that the alkali metal is sodium.

3. A method of preparing an amalgam of alkali metal, mercury and aluminum which comprises admixing said alkali metal, mercury and aluminum in an inert atmosphere at an elevated temperature followed by cooling said admixture while maintaining said inert atmosphere to form a solidified amalgam product.

4. The method of claim 3 wherein said elevated temperature is about  $200^\circ \text{C} \pm 10^\circ \text{C}$ .

\* \* \* \* \*

**United States Patent** [19][11] **4,231,891****Beckert et al.**[45] **Nov. 4, 1980**

[54] **SOLID COMPOSITIONS FOR GENERATION OF GASES CONTAINING A HIGH PERCENTAGE OF HYDROGEN OR ITS ISOTOPES**

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**William H. Barber**, Brandywine, Md.; **Ottmar H. Dengel**, Front Royal, Va.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, D.C.

[21] Appl. No.: **916,423**

[22] Filed: **Jun. 16, 1978**

[51] Int. Cl.<sup>3</sup> ..... **C01B 1/07**

[52] U.S. Cl. .... **252/188; 149/87;**  
252/188.3 R; 423/648 R

[58] Field of Search ..... **252/188, 188.3 R;**  
423/248, 648 R; 149/87

[56]

**References Cited****U.S. PATENT DOCUMENTS**

3,734,863	5/1973	Beckert et al. ....	252/188
3,862,052	1/1975	Beckert et al. ....	252/188
3,931,395	1/1976	Beckert et al. ....	423/648 R
3,948,699	4/1976	Ayers et al. ....	423/648 R
3,948,700	4/1976	Ayers et al. ....	423/648 R
3,977,990	8/1976	Beckert et al. ....	252/188
4,005,185	1/1977	Ishizaka .....	423/648 R
4,022,705	5/1977	Beckert et al. ....	252/188.3 R
4,064,226	12/1977	Beckert et al. ....	423/648 R

*Primary Examiner*—Benjamin R. Padgett

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*Attorney, Agent, or Firm*—Sciascia R. S.; A. L. Branning; H. B. Field

[57]

**ABSTRACT**

Solid compositions which, when heated to initiate the reaction between the components of the compositions, generate gases containing a high percentage of hydrogen or hydrogen isotopes. The compositions comprise intricate mixtures of certain metal powders and certain ammonium or hydrazinium salts.

**12 Claims, No Drawings**

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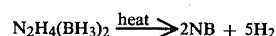
# SOLID COMPOSITIONS FOR GENERATION OF GASES CONTAINING A HIGH PERCENTAGE OF HYDROGEN OR ITS ISOTOPES

## BACKGROUND OF THE INVENTION

This invention relates generally to the art of gas generation and more particularly to compositions and methods for generating hydrogen gas.

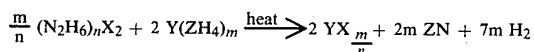
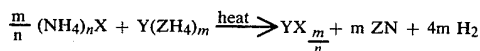
There are currently only a limited number of methods available to produce hydrogen on a small scale. For example, hydrogen gas is generated by the reaction of metals or metal hydrides with acids, bases, water, alcohols, etc. Hydrogen gas can also be stored in and released from pressurized gas cylinders. However, these methods are not applicable when severe weight and/or volume restrictions are imposed on a system which must generate relatively small amounts of hydrogen gas (up to about 250 liters) in a short time (less than one minute). The following example will illustrate this point: The exothermic reaction of  $\text{LiH} + \text{H}_2\text{O} \rightarrow \text{LiOH} + \text{H}_2$  with 27 kcal/mole hydrogen. Assuming 100 percent completion of the reaction without an available external heat sink, then well over 300 grams of water would be needed to produce 1 mole of hydrogen gas (i.e., 18 grams of water as reactant and the remainder for a heat sink) in order to prevent boiling of the water and the formation of a hydrogen/steam mixture. This means that the weight/volume ratio (reactants (grams) per liter of hydrogen generated) is greater than 14 grams per liter.

Another reaction which has been proposed to generate hydrogen is based on the thermal decomposition of hydrazine bisborane. This reaction is represented by the following equation:



Although in theory this reaction is very favorable in terms of hydrogen produced per gram of reactant (weight-volume ratio is 0.54 gram per liter assuming 100 percent yield), the temperature required to keep the reaction going is high enough to melt glass fiber cloth and the hydrogen produced is at its ignition temperature. In addition, hydrazine bisborane is not commercially available and it is difficult to handle because of its instability.

U.S. Pat. Nos. 3,734,863, 3,862,052, 3,931,395, 3,977,990, and 4,022,705 to Beckert et al., which are incorporated herein by reference, teach various hydrogen generating compositions and their methods of preparation. More specifically, U.S. Pat. Nos. 3,734,863, 3,862,052, and 3,931,395 disclose reacting ammonium or hydrazinium salts with suitable complex metal hydrides as expressed by the following general formulas and general equations:



where x is an acid group such as an inorganic acid group like halogen (Cl, Br, F), sulfate ( $\text{SO}_4$ ), and the like, n is the valency of the acid group, Y is a mono- or divalent metal capable of forming complex hydrides,

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such as alkali and alkaline earth metals like Li, Na, K, Mg, Ba, Ca, etc., m is the valency of said metal and Z is a trivalent metal capable of forming complex hydrides, such as B, Al, and the like. Similarly, U.S. Pat. No. 3,977,990 to Beckert et al. teaches that the hydrogen gas evolution rates and the gas temperatures of certain hydrogen gas generating compositions are modified by adding compounds such as  $\text{LiAlH}_4$  which thermally decompose in the reaction zone producing hydrogen while lowering the reaction temperature; and certain acetates, certain metal oxides, and the like which, when added in relatively small amounts accelerate the hydrogen gas evolution rate.

While these methods and compositions are satisfactory in providing hydrogen at a fast rate from solid, storable compositions, complex metal hydrides are commercially available only to a limited extent, and they are relatively expensive. Especially for large-scale uses such as in laser or fuel cell applications it is highly desirable to use compositions that are less costly.

## SUMMARY OF THE INVENTION

Accordingly, there is provided by the present invention solid compositions for generating gases containing a high percentage of hydrogen or hydrogen isotopes, comprising an intimate mixture of at least one metal powder selected from the group consisting of magnesium, aluminum, vanadium, zirconium, and titanium and at least one salt selected from the group consisting of  $(\text{NH}_4)_n\text{X}$  and  $(\text{N}_2\text{H}_6)_n\text{X}$  wherein H stands for hydrogen and its isotopes, X is an inorganic acid group and n is the valency of said inorganic acid group and wherein said compounds are present in about stoichiometric amounts or are present in amounts such that there is a stoichiometric excess of one of the components.

## OBJECTS OF THE INVENTION

Therefore, one object of the present invention is to provide a low cost source of gaseous hydrogen, hydrogen isotopes, or mixtures thereof.

Another object of this invention to provide novel compositions and methods for generating gaseous hydrogen isotopes or mixtures thereof.

Still another object of this invention is to provide compositions and methods for generating gaseous hydrogen isotopes or mixtures thereof which are particularly applicable where small amounts of gas are required in a very short time.

A further object of this invention is to provide methods for generating gaseous hydrogen isotopes or mixtures thereof in which the ratio of weight of reactants to volume of gas generated is smaller than heretofore attained.

Yet another object of this invention is to provide a method for generating gaseous hydrogen isotopes or mixtures thereof which is economical and relatively safe.

Still another object of this invention is to provide compositions and methods for generating gaseous hydrogen, hydrogen isotopes, or mixtures thereof suitable for use in laser applications, fuel cells, nuclear reactions, chemical reactions.

A further object of the present invention is to provide additional compositions and methods for generating hydrogen, hydrogen isotopes, or mixtures thereof for use in fluoric devices and mechanical power sources.

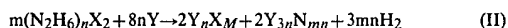
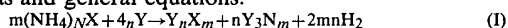
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Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description of the preferred embodiments.

### DESCRIPTION OF THE PREFERRED EMBODIMENTS

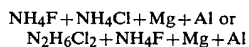
The method of this invention is based on a solid state reaction between two or more suitable components. Particularly, the component ingredients employed in the mixtures and methods of the present invention and the reactions by which the desired gaseous hydrogen isotopes of deuterium and tritium or isotopes mixtures generated are expressed by the following general formulas and general equations:



where H stands for hydrogen and its isotopes, X is an acid group such as an inorganic acid group like halogen (Cl, Br, F, etc.), sulfate ( $\text{SO}_4$ ) and the like, n is the valency of the acid group Y is a metal power such as magnesium, aluminum, vanadium, zirconium and titanium and m is the valency of the metal under the reaction conditions. The compounds employed in the mixture of this invention are either commercially available or may be prepared by conventional means. The compositions tested have been found to be stable at ambient temperature and to react at higher temperatures ranging from about 160° C. to about 400° C., producing gases of varying compositions. For example, the composition consisting of Mg and  $\text{NH}_4\text{Cl}$  in stoichiometric amounts starts to react at approximately 200° C. producing a gas mixture consisting of approximately 85%  $\text{H}_2$  and 15%  $\text{N}_2$ . The gas temperature is approximately 350° C.

The gas generating reactions of this invention are initiated by locally heating the mixture of the component reactants to reaction temperature. This can be accomplished by any suitable heat source such as a resistance heater fabricated from Nichrome wire, a pyrofuse, and electrical squib, a mechanical squib, or the like. In addition, ordinary percussion caps and igniter pills such as  $\text{BaCrO}_4/\text{Zr}$  may be utilized if desired.

A temperature of at least about 160° C. is generally required to initiate the reaction. The component ingredients are generally intimately mixed in stoichiometric amounts according to the aforeidentified general equations. However, it may be desirable to employ an excess of one of the components. For example, one reason why one would want an excess of one of the components is to more efficiently utilize the more expensive components. Furthermore, the use of mixtures of three or more components is also within the scope of the present invention. For example a mixture of



may be employed as gas generating compositions in the method of the present invention.

These hydrogen generating compositions may be encapsulated or otherwise packaged in such a manner that they may be adapted as a convenient source of predetermined quantities of hydrogen for the inflation of lighter-than-air balloons or other inflatables, fluoric devices, mechanical power sources, etc., as well as other military and commercial uses. These compositions may be utilized as powders or they may be pressed

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into pellets to facilitate handling and improve storage stability and safety characteristics, as well as to achieve a more uniform rate of gas evolution after initiation. Coating of one or all of the starting components with a small amount (usually about 0.5 to 5 weight percent) of a suitable polymer prior to mixing has been found to further improve the handling and storage characteristics. Examples of such suitable polymers are polystyrene, polyethylene, polybutadiene, hydroxyvinyl resins, and polycarbonates. Such coating is especially beneficial for components which are sensitive to moisture.

It is also part of the instant invention to optionally use binders or plasticizers to improve handling and or mechanic stability. Any binder compatible with the rest of the composition may be used, such as polystyrene, styrene-isobutylene copolymers, or others. Up to about 15 percent by weight of said composition is appropriate. Similarly, any plasticizer may be used so long as it is compatible with the rest of the composition. The preferred amount of plasticizer is up to about 30 weight percent of said binder. In addition, any solvent which dissolves the binder and is compatible with the rest of the composition can be used to facilitate processing of the composition. Special precautions might be necessary in the selection of binders, plasticizers, additives and solvents when high-purity gases are desired. For example, when pure deuterium gas is desired it is beneficial to either use deuterated binders, plasticizers, additives and solvents or to use binders, plasticizers, additives and solvents which do not contain any hydrogen exchangeable under the conditions of use such as polyfluorinated compounds.

Small particle sizes (100) of the ingredients are desirable as large particle sizes generally decrease rate and yield. Although, in general, a small particle size of the gas generator ingredients is therefore desirable to obtain a fast and nearly complete reaction, large particle sizes might be useful for special purposes, e.g. to slow down the reaction, or to obtain a specific grain structure.

The material is conveniently prepared as a slurry of the components in an inert solvent such as toluene which contains the dissolved binder and plasticizer. After evaporation of the solvent in vacuo, the material is ground in a blender and then pressed to form slugs. Depending on the nature of the material and the intended application other mixing and shaping techniques can be used, such as casting, extrusion, or inert diluent mixing.

After generation, the gases can be cooled by heat exchangers and/or heat sink arrangements containing materials having a high specific heat such as copper, nickel, or cobalt, or materials which exhibit an endothermic phase change between ambient and the desired temperature, such as low-melting materials which preferable have high heats of fusion and heat capacities (Wood's metal, Rose's metal, or chemical compounds such as  $\text{Na}_2\text{HPO}_4 \cdot 2\text{H}_2\text{O}$ ) or low-boiling liquids.

Additives which decompose during the reaction under gas evolution can be added directly to the basic mixture, or they can be physically separated from the basic mixture (e.g. confined in tubes embedded in the basic mixture, or by microencapsulation). This separation might be desirable in case of limited compatibility of the additives with the basic mixture.

The general nature of the invention having been set forth, the following examples are presented as specific illustrations thereof and also so that the invention be

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better understood. Furthermore, it will be understood that the invention is not limited to these examples but is susceptible to various modifications that will be recognized by one of ordinary skill in the art.

#### EXAMPLE I

Anhydrous ammonium chloride is mixed with magnesium powder (10% excess over stoichiometric amount) in a toluene solution of isobutyl-styrene copolymer and conco oil as plasticizer, the solvent is evaporated in vacuo at ambient temperature, the resulting dry mass pulverized and pressed into the desired shape. When fired in a suitable light weight aluminium gas generator case such as described in U.S. Pat. No. 3,898,048 to Barber et al included herein by reference a gas consisting to approximately 85% of hydrogen is produced at a rapid rate and a temperature of approximately 350° C. The gas yield is about 0.5 l/g of mixture.

#### EXAMPLE II

The process is repeated with ammonium bromide and aluminium powder as the main ingredients. The gas yield is approximately 0.3 l/g of mixture.

As will be evident to those skilled in the art, various modifications can be made in light of the foregoing disclosure without departing from the scope and spirit thereof.

What is claimed and desired to be secured by Letters Patents of the United States is:

1. Solid compositions for generating gases containing a high percentage of hydrogen or hydrogen isotopes comprising an intimate mixture of at least one metal powder selected from the group consisting of magnesium, aluminum, vanadium, zirconium, and titanium and at least one salt selected from the group consisting of an ammonium salt of the formula  $(\text{NH}_4)_n\text{X}$  and a hydrazin-

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ium salt of the formula  $(\text{N}_2\text{H}_6)_n\text{X}$  wherein H stands for hydrogen and its isotopes, X is an inorganic acid group and n is the valency of said inorganic acid group and wherein said compounds are present in about stoichiometric amounts or are present in amounts such that there is a stoichiometric excess of one of the components.

2. A composition according to claim 1 wherein said compounds are present in stoichiometric amounts.

3. A composition according to claim 1 wherein said compounds are present in amounts such that there is a stoichiometric excess of one of the components.

4. A composition of claim 1 wherein said acid group is selected from the group consisting of halogen and sulfate.

5. A composition of claim 4 wherein said halogen is selected from the group consisting of Br, F, and Cl.

6. A composition of claim 5 wherein said halogen is chlorine and said metal is magnesium.

7. A composition of claim 4 wherein said salt is an ammonium, salt.

8. A composition of claim 4 wherein said salt is a hydrazinium salt.

9. The composition of claim 1 wherein at least one component of the mixture is coated with a polymer selected from the group consisting of polystyrene, polyethylene, polybutadiene, polycarbonate and hydroxyvinyl resins.

10. The composition of claim 1 further comprising a binder up to about 15% by weight of said compositions.

11. The composition of claim 10 additionally comprising a suitable plasticizer up to about 30% by weight of said binder.

12. The composition of claim 10 wherein said binder comprises an isobutyl-styrene copolymer.

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**United States Patent** [19][11] **4,256,060****Kelly**[45] **Mar. 17, 1981****[54] MANIFOLD HYDROGEN GENERATOR  
UNITS FOR AUTOMOTIVE I.C. ENGINES****[76] Inventor:** Donald A. Kelly, 58-06 69th Pl.,  
Maspeth, New York, N.Y. 11378**[21] Appl. No.:** 66,243**[22] Filed:** Aug. 13, 1979**[51] Int. Cl.<sup>3</sup> .....** F02B 43/08**[52] U.S. Cl. ....** 123/3; 123/DIG. 12;  
48/81; 48/102 A**[58] Field of Search .....** 123/3, 1 A, DIG. 12;  
48/81, 64, 65, 66, 102 A**[56] References Cited****U.S. PATENT DOCUMENTS**

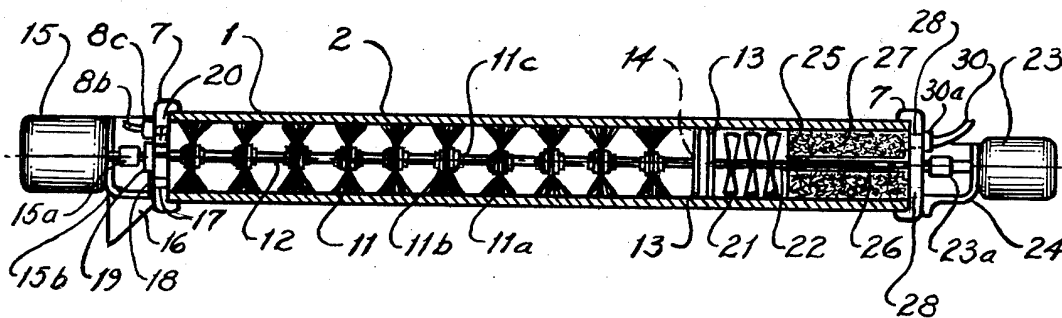
1,966,345	7/1934	Harrell .....	123/3
3,653,364	4/1972	Bogan .....	123/3
3,682,142	8/1972	Newkirk .....	123/3
3,717,129	2/1973	Fox .....	123/3
4,086,877	5/1978	Henkel .....	123/DIG. 12

**OTHER PUBLICATIONS****"Partial Hydrogen Injection"**, by Breshears, Cotrill and  
Rupe, JPL Lab., Oct. 14, 1973.*Primary Examiner*—Ronald B. Cox**[57]****ABSTRACT**

The manifold hydrogen generator units for automotive I. C. engines are intended to provide a supplementary hydrogen fuel supply for conventional automotive I. C. engines, in addition to any primary fuel including gasoline, gasohol or hydrogen.

The hydrogen is produced in a three stage process starting with the conversion of water to steam by means of multiple coils of copper tubing closely fitted to the exhaust manifold(s) of the I. C. engine. The steam is directed into one or two reactor cylinders containing rotating wire brushes axially disposed within the reactor cylinder(s) which remove a portion of the oxygen through progressive oxidation of the iron wire brushes. Periodic forced purging of the wire brushes is provided by combined aeration and vibrating of the rotating brushes.

A final reforming stage of the partially reformed steam/hydrogen flow is obtained by steel wool packs which are periodically replaced.

**10 Claims, 8 Drawing Figures**



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FIG. 1

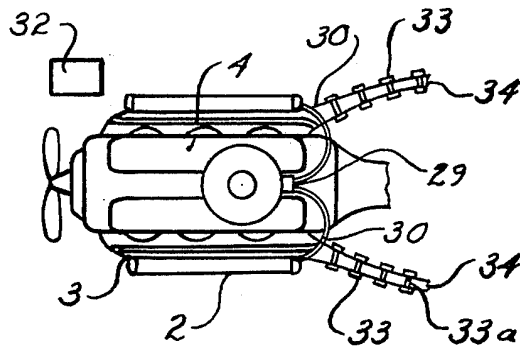


FIG. 2

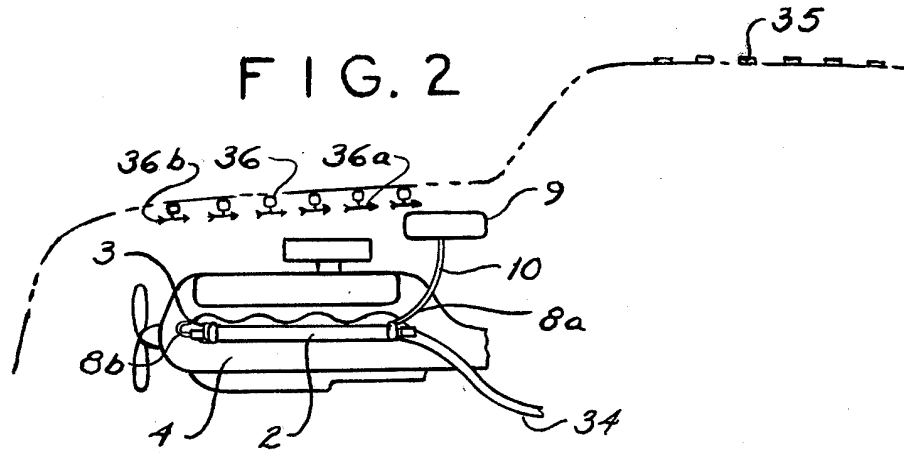
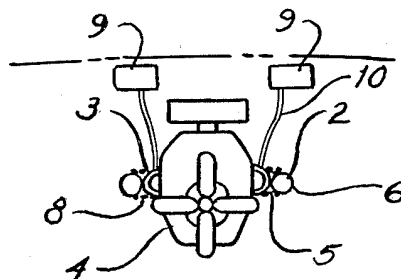


FIG. 3



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FIG. 4

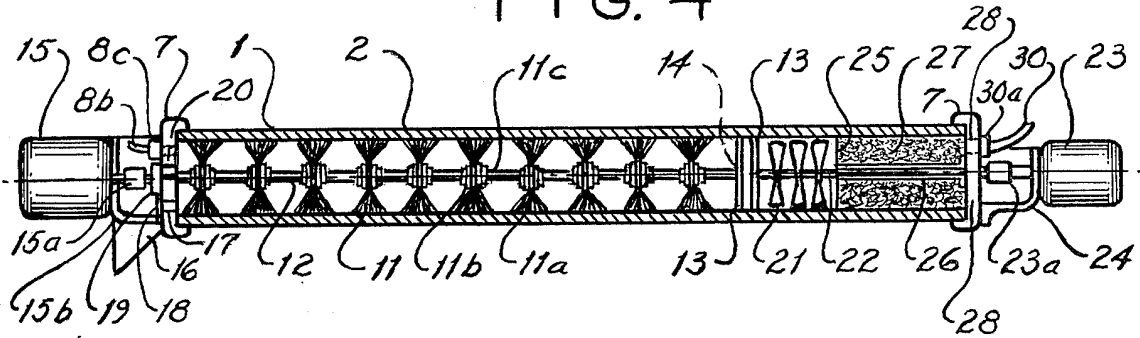


FIG. 5

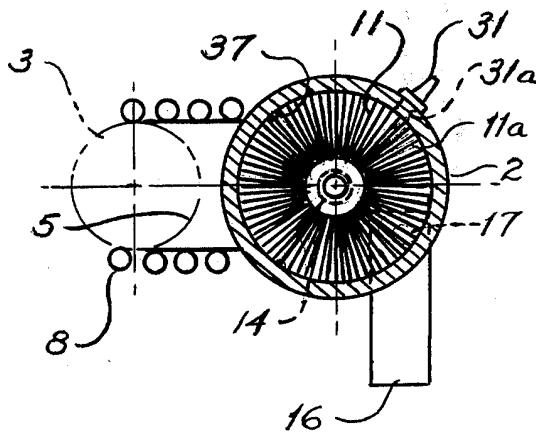


FIG. 6

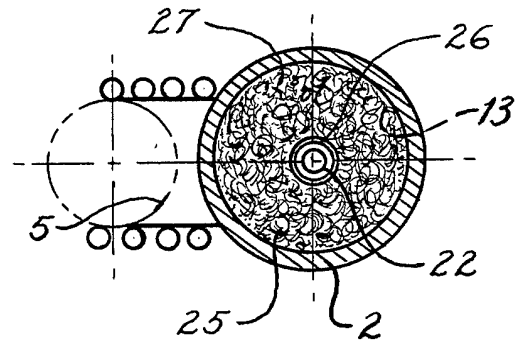


FIG. 7

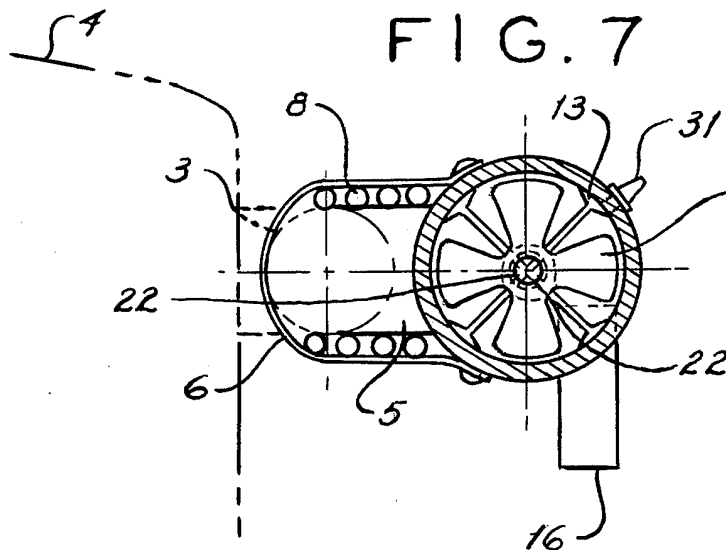
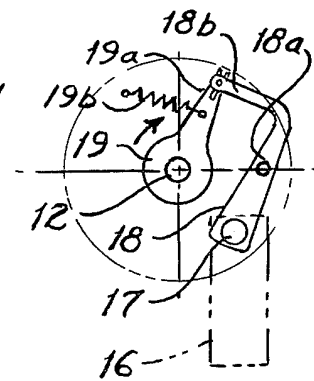


FIG. 8



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## MANIFOLD HYDROGEN GENERATOR UNITS FOR AUTOMOTIVE I.C. ENGINES

### BACKGROUND OF THE INVENTION

The use of hydrogen gas as a supplemental fuel in addition to gasoline or gasohol offers some distinct advantages for present and future motor vehicle operation in the light of constantly increasing gasoline prices and projected supply diminishment. Hydrogen fuel can be readily adapted for use in conventional automotive I.C. engines with only minor adjustments necessary for its proper combustion along with gasoline or gasohol.

Since hydrogen gas burns cleanly with water vapor left as the major exhaust component, the total exhaust emission levels from such combined fuel for the engine will be correspondingly lower. These two advantage alone should be more than enough for hydrogen fuel to gain wide scale acceptance as a supplementary automotive fuel, but in addition hydrogen can be readily generated on-board the vehicle with retrofitted components, unlike any other fuel means now known.

The main effort towards the development of practical automotive hydrogen fueled vehicles has been by way of the storage of the gas on board the vehicle as the primary fuel source. The most prominent method used for the storage of the gas has been the utilization of various types of metal hydrides, which act as hydrogen gas "sponges" to absorb and release the gas as required.

Such groups as Brookhaven Labs, Billings Corporation, and Mercedes Benz have adopted this on-board hydrogen storage method because of its workability, basic safety and useful gas volume storage capacity.

With the advent of iron-titanium hydride (Ti-Fe), developed at Brookhaven Laboratories, the on-board H<sub>2</sub> storage approach for vehicular applications has become practical, since hydrogen can be absorbed and released from the storage volume at relatively low temperatures and pressures. While these various plus features for hydride storage make its use attractive for many vehicular applications there remains the major problem of hydrogen distribution to motorists which will be decades away from realization, if at all. The hydrogen distribution problem means that automotive hydrogen storage alone, cannot be considered as a short-term solution to ever increasing gasoline prices and the progressively decreasing supply.

The wide scale distribution of hydrogen as an automotive fuel will require long term capital investment by the industry, while on the other hand, on-board hydrogen generation equipment is centered on the first cost of operating components only, which do not now appear to be beyond the range of reasonable first cost amortization, based on the long-term gasoline cost savings involved.

Various types of hydrogen fueled vehicles have been proposed and described over the years with the prospects of substituting this minimum polluting fuel for high cost, polluting gasoline fuel, as presently used. There has been considerable reluctance towards the acceptance of hydrogen as a fuel because it is believed to be dangerous to handle and use, (the Hindenburg syndrome) but if carefully generated and used immediately in minimum volumes, adequate safety is assured.

Considerable theoretical work has been done toward utilizing hydrogen as an alternate fuel for conventional I.C. engines with numerous hydrogen generation and storage methods proposed and developed. All of the

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economically practical and experimental methods for hydrogen generation have been described in about twenty prior U.S. and foreign patents for alternate vehicular propulsion. Several of these prior patents deal with heat recovery from the engine exhaust manifolds to drive various types of closed cycle engine loops, which in turn are used to provide a low voltage D.C. power source required for conventional electrolysis cells, as the hydrogen generation means.

Another on-board hydrogen generation means which has received moderate attention and prototype development effort is the gasoline reforming process in which a small flow volume of gasoline is broken down into its basic components in a thermal reactor, with hydrogen gas produced along with varying amounts of hydrocarbon by-products. Successful prototypes have been evolved using this process, but the present equipment is cumbersome and will require extensive size reduction and improvement before any possible commercialization stage is reached.

It should be realized that the gasoline reforming process for automotive applications starts out with a negative position, since it takes away a small portion of the total gasoline flow which we are attempting to conserve as an overall goal for an economical automotive supplemental fuel system.

The electrolysis process for automotive applications, previously mentioned, is not handicapped in this way, as it is clearly separate from the primary fuel supply, and although it is mainly dependent on I.C. engine operation, it is not dependant on the primary fuel means in any way. The major problem facing on-board hydrogen generation using the electrolysis process is that of the very large electrical wattage required and the relatively slow rate of hydrogen flow produced which is not now compatible with normal I.C. engine operation.

In a modified steam-on-iron hydrogen generation process,—Bogan,—U.S. Pat. No. 3,653,364, has described the adaptation of this known H<sub>2</sub> industrial process to an automotive application. Although this process art is novel in several respects it does not solve all the different problems involved in such a limited space and operating environment for this normally large scale industrial process. Firstly, the steam-on-iron process usually operates with the best effectiveness in the superheated steam ranges which are not economically possible for any automotive applications. Another major difficulty not considered in this art is that of the intermittent deoxidation/aeration of the iron volume-(contact mass), which is not feasible with stationary small iron balls, as described.

The oxidation of all the iron balls will gradually diminish as they all become fully rusted and the hydrogen liberation will correspondingly diminish and eventually come to a halt. If all of the small iron balls are uniformly agitated and periodically abraded to remove the rust-/and/or accumulations in some way, then this method may be reasonably successful for nearly continuous operation if a high temperature steam flow is provided within a suitable reaction unit.

High energy levels are required to produce the necessary steam reforming, and while a portion of the required heat energy can be recovered from the exhaust manifold(s), as described by Bogan, an additional high heating source will be required to maintain the thermal reaction for an automotive version of this industrial process. The use of electrical resistance heaters pow-

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ered by the vehicle's only battery, as described by Bogan, is not considered practical in view of their constant high discharge rate from the single battery in the vehicle. It is not feasible to heat water into steam by electrical resistance heating as described by Bogan, and a more practical approach must be sought to produce the necessary steam flow.

In an earlier U.S. Pat. No. 1,966,345, by Harrell, iron filings are fully packed within a pipe section centrally located inside the exhaust manifold of an auto engine. A small steam flow is produced within the exhaust manifold from a raised water reservoir which gravity feeds a small water flow into the manifold and pipe section. While the steam flow over the iron filings will produce hydrogen liberation, again no provision for periodic purging is evident in this hydrogen generation arrangement, so that it falls short of a practical and continuous supplementary hydrogen fuel system for vehicles. This earlier art is more effective from the standpoint of heat transfer than the art of Bogan, since the iron filings within the pipe section is fully enclosed within an enlarged special exhaust manifold on a conventional I.C. automotive engine. The art of Bogan does not take the fullest advantage of the hot exhaust manifold(s) as does Harrell's art.

It can be appreciated that the very high exhaust manifold temperatures are attractive heat sources especially when no operating performance penalty is imposed on the vehicles engine or drive train. In spite of this attractive heat source for hydrogen liberation by steam reaction, an additional heat source will be required for a successful hydrogen fuel flow by this known method. The use of several electrical resistance heaters as the added heating means can be considered only if a second 12 volt automotive battery is included along with a constant and reliable recharging means for this second battery.

Such unusual electrical sources as thermoelectric and photovoltaic cells and air driven generators revolved by the moving vehicle can be useful electric recharging sources for this specific application. Since the multiple electrical heaters cause a large electrical drain on the secondary battery, it will be necessary to provide electrical recharging from all three electrical sources previously described.

The authority for the contention that an effective deoxidation aeration phase for the steam-on-iron process is necessary comes from "Bailey's Industrial Oil and Fat Products,"—Third Edition,—on Hydrogenation, Pg. 851, ie: "Failure to remove these accumulations-(carbon, sulfur, rust) results in virtually complete inactivation of the control mass (iron balls, iron filings)." "It is customary to follow each steaming period with a short period of aeration (purging) during which time air is blown through the ore (contact mass) to burn off the carbon and sulfur accumulations."

While the purging of the contact iron mass in the industrial process can be readily accomplished, it becomes a difficult task to achieve for an automotive-sized unit(s) where both a lack of space along with purging provision and effectiveness become major difficulties.

#### SUMMARY OF THE INVENTION

The manifold hydrogen generator units for automotive I.C. engines are advocated as a means of substantially reducing the gasoline fuel consumption in conventional I.C. engine powered vehicles of all types. This present arrangement offers a practical way of adopting

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hydrogen gas as a supplementary or primary automotive fuel, and envisions 100% hydrogen utilization for many automotive applications during the twenty-first century.

The small hydrogen gas flow volume to the automotive I.C. engine provided by this system is produced in a three stage process, with the first being the conversion of water into steam by means of multiple turns of small diameter tubing around the engine's exhaust manifold(s). The multiple turns of tubing must be closely wound and in full contact with the exhaust manifold(s), either spirally or longitudinally depending on the type of manifold and available clearance space around it. Most current automotive engine exhaust manifolds have various adjacent components around them which complicate the clear placement of the water-steam tubing so that the method of tubing application must be kept flexible, and easily removably if possible.

Several water containers for the water supply to the tubing inlet must be mounted as high as practical within the engine compartment so that a constant gravity feed water supply to the water/steam tubing is maintained. The water supply to the tubing inlet must enter at the rear of the manifold(s) with a minimum of  $2\frac{1}{2}$  turns (longitudinal) around the manifold with the steam exit end of the tubing at the front of the exhaust manifold(s). If the tubing is spirally wound around the exhaust manifold(s), a minimum of nine loops will be required, or three loops per manifold section of a V-eight cylinder I.C. engine. A straight upright six cylinder engine will accommodate a total of ten tubing loops, or two loops per manifold section.

The steam generated within the final tubing loop is directed into the front end of the reactor cylinder(s) where it flow through uniformly spaced rotary iron wire brushes closely fitted within the inside diameter of the iron reactor cylinder(s).

The reactor cylinder(s) are standard two inch or two and one-half inch diameter (I.D.) iron pipes approximately one and one-half feet long, fitted with two threaded and sealed end caps. Several conveyor fans are located toward the rear of reactor cylinder(s) to assure continuous steam/gas flow through the cylinders and into the engine's intake manifold.

The reactor cylinders are adapted to the engine's exhaust manifolds by means of matched adapter mounts which are elongated metal pieces with two opposite semi-circular concave cavities which match the outside diameters and shape of the exhaust manifolds and reactor cylinders, respectively. The adapter mounts are permanently fastened to the reactor cylinders and secured the the exhaust manifold(s) with several adjustable clamps.

When the water/steam tubing is in a longitudinal form it must partially cover the matched adapter mounts and partially contact the exhaust manifolds, but when the tubing is spirally wound around the manifolds then clearance for the tubing loops must be provided within the matched adapter mounts.

The wire brushes consist of multiple fine iron wires in a fairly dense radial form and held together by two hub discs. Each of the rotary brushes must lightly contact the reactor pipe I.D. so that all accumulations can be periodically removed. A central shaft connects all the rotary brushes together with the two hub discs cinched to the shaft. The wire brush shaft which does not normally revolve, is supported in sleeve bearings by the front end cap and an internal support spider, and is

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brought into contact with the constantly revolving rear conveyor fan shaft by a small solenoid mounted on the front end cap.

The front end cap also mounts the front steam entrance tubing line and front purging air funnel, along with the exhaust gas tubing line from the exhaust manifold(s).

A second internal support spider is required to support the conveyor fan shaft at the internal end while the other, rear end cap supports this shaft at the outer, rear end. A small D.C. motor and reduction gear train is secured to the rear end cap which revolves the conveyor fan shaft at a constant speed.

A coupling set is used to intermittently connect the conveyor fan shaft with the front wire brush shaft, which is reciprocated to be periodically driven by the rear conveyor fan shaft. A steel screen disc is located directly behind the last, rear conveyor fan to retain the steel wool pack which provides the final steam reforming stage of the reactor cylinder(s). The steel wool pack is retained by the rear end cap which is threaded and sealed on to the rear of the reactor pipe section.

A larger diameter outlet tubing connection is fitted to the rear end cap with the tubing routed to a convenient location on the intake manifold. This tubing line should be formed with generally large radii so that the gas flow is not impeded, and it must be well insulated so that the gas flow is not cooled excessively. It will be desirable to have a quick-connection fitting for the outlet tubing line, since the rear end cap must be periodically removed to replace the rusted steel wool packs.

The front purging air inlet funnel is formed as a rectangular air scoop facing forward to draw in and slightly compress the air flow, periodically, to coincide with the rotation of the multiple rotary wire brushes, actuated by the front solenoid. An air inlet gate at the base of the air inlet funnel is normally closed and will be opened by the front solenoid, as the rotary iron wire brushes are revolved. This combined action of the forced air inlet and the revolving of the brushes against the pipe inside diameter comprise the periodic purging phase of the process.

Approximately five electrical resistance heaters with threaded bases are uniformly located along the length of the reactor cylinder(s), and are screwed into the side wall, so that additional heating is available within the reactor cylinder to assure that a necessary high heating level is attained for the steam reforming process. These electrical heaters must be threaded into the reactor cylinders after the rotary brushes and conveyor fans are in place within the cylinder (s), and all removed prior to the removal of the rotary brush and conveyor fan assemblies for servicing.

The electrical resistance heaters receive electrical power from the second battery within the vehicle which is recharged by several electrical sources such as thermoelectric cells mounted on the exhaust pipes of the vehicle, multiple photovoltaic cells on the vehicle roof, and by multiple air-driven disc generators within the engine compartment of the vehicle.

A copper tubing line(s) of about the same diameter, (approximately  $\frac{1}{4}$  inch) as the water/steam tubing is used to recycle a small portion of the exhaust gases within the rear of the exhaust manifold back to the entrance front end cap of the reactor cylinder(s). The exhaust gases, mainly carbon monoxide, are mixed with the incoming steam flow to produce a gas mixture which can be partially reformed into hydrogen gas and

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residual gases. It is important that both a high temperature and fairly high flow velocity be maintained for the mixing steam and exhaust gases passing through the main reactor section, so that the reforming gas mixture can pass through the final reforming steel wool packs stage without excessive impedance.

Several design variations from this previously described process unit(s) arrangement can be made to simplify or improve the performance of the process such as utilizing a small D.C. motor instead of the front solenoid, to intermittently revolve the rotary wire brushes. This substitution may prove to be more reliable since no reciprocation of the rotary wire brush shaft is involved, and no need for the meshing of the front and rear shafts at the couplings, as previously described. If this arrangement is adopted it will be necessary to have a manual control cable to open the front air inlet gate, at the same time that the switch is thrown to start the brush drive motor.

Another variation of the original arrangement could consist of adopting a manual control, simultaneously, for both the intermittent reciprocation of the rotary brush shaft and the opening of the front air inlet gate. Other variations and improvements on the original arrangement may be possible as the system/process is evolved.

In the first stage of operation, the water from the gravity-feed water containers is directed into the water/steam tubing loops where the hot engine exhaust manifold(s) convert it into steam in the last loop. The tiny steam flow is fed into the reactor cylinder(s) in the second stage of the process, where it is mixed with a nearly equal flow volume of exhaust gases from the exhaust manifold(s).

This gaseous mixture is forced through the reactor cylinder(s) by the revolving conveyor fans toward the rear end of the cylinder(s), and is partially reformed by the partial oxidation of the multiple rotary iron wire brushes and the high heating level within the reactor cylinder(s).

In the third and final stage of the process, the partially reformed gaseous mixture is further reformed when the gaseous mixture is passed through the rear steel wool pack. The steel wool pack will become oxidized, so that the remaining gas flow contains a higher percentage of hydrogen gas from the steam/CO reinforcing process. This reformed gas flow is drawn into the engine's intake manifold by the intake partial vacuum, and is mixed with the incoming primary engine fuel.

It is a principal objective of the invention to provide a significant decrease in the normal gasoline fuel consumption for most types of automotive vehicles.

A further objective of the invention is to provide a progressively increasing volume of hydrogen gas to gasoline ratio mixtures, towards an eventual 100% hydrogen fuel means as the process units are further evolved.

It should be understood that design variations may be made in the detail features of the manifold hydrogen generator units, without departing from the spirit and scope of the invention, as disclosed herein.

Several Disclosure Documents have been filed with the Office which describe the full unit and portions of the present invention.

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## Disclosure Document

- (1) No. 081,814—Automotive Steam Reactor Unit for On-Board Hydrogen Power  
 (2) No. 079,804—Automotive Dual-Mode Hydrogen Generation System.

## DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top view of two manifold hydrogen generator units in place on an automotive I.C. engine.

FIG. 2 is a side elevation view of a manifold hydrogen generator unit in place on an automotive I.C. engine.

FIG. 3 is a front view of two manifold hydrogen generator units in position on an automotive I.C. engine.

FIG. 4 is an enlarged side cross-section view of a manifold hydrogen generator unit.

FIG. 5 is an enlarged cross-section view through a single rotary iron wire brush of a single manifold hydrogen generator unit.

FIG. 6 is an enlarged cross-section view through the steel wool pack, as the final stage of the manifold hydrogen generator unit.

FIG. 7 is an enlarged cross-section view through a single conveyor fan of a single manifold hydrogen generator.

FIG. 8 is a cross-section through the clutch mechanism.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

The multiple hydrogen generator unit (s) 1, are comprised of one or two reactor cylinder(s) 2, per vehicle, which are fitted on to the existing exhaust manifold(s) 3, of an automotive I.C. engine 4. The reactor cylinder(s) 2, are adapted to closely match and contact the engine's exhaust manifold(s) 3, by means of adapter mounts 5, which are permanently fastened to the reactor cylinder(s) 2. The adapter mounts 5, are secured to the exhaust manifold(s) 3, by several adjustable clamps 6.

Two identical end caps 7, are threaded on to the reactor cylinder(s) 2, which are approximately two and one-half inches in diameter (I.D.), by about eighteen inches long and made of standard iron pipe (ungalvanized on the I.D.).

Multiple turns of small diameter tubing 8, are closely wound around, and in full contact with both the adapter mounts 5, and the exhaust manifold(s) 3, so that water from raised plastic reservoirs 9, is flashed over to steam in the final tubing loop of the water/steam tubing loops 8.

The water from the reservoirs 9, is conveyed to the inlet tubing loops 8a, by flexible plastic tubing 10. The inlet tubing loop 8a, is located at the top, rear of the exhaust manifold(s) 3, with a minimum of two and one-half turns or loops made around the exhaust manifold(s) 3. The exit end 8b, of the tubing loops 8, is located at the front of the exhaust manifold(s) 3, with the tubing entering the reactor cylinder(s) 2, through the front end cap 7, by means of a threaded connector 8c.

Multiple, uniformly spaced rotary iron wire brushes 11, are closely fitted and in light rubbing contact with the inside diameter of the reactor cylinder(s) 2, and are all revolved by a front central shaft 12, which protrudes through the front of the front end cap 7. A spider support 13, with a centrally located ball or sleeve bearing 14, is closely fitted into the inside diameter of the reac-

tor cylinder(s) 2, and supports the inner end of the front central shaft 12. Another similar ball or sleeve bearing 14, is centrally located within the front end cap 7, to support the front end of the front central shaft 12.

The multiple iron wire brushes 11, are made of a fine iron wire 11a, arrayed in a uniformly dense radial form, and held together with two identical hub discs 11b. The front central shaft 12, should be partially threaded within the reactor cylinder 2, area, so that each brush 11, assembly may be locked into position on the front central shaft 12, with locknuts 11c, on both sides of the hub discs 11b.

The multiple iron wire brushes extend approximately three-quarters of the length of the reactor cylinders(s) 2, so that an adequate iron wire surface area is provided for the steam am reforming process for the unit(s) 1.

A small 12 volt D.C. motor 15, is connected to the front central shaft 12, front protrusion by means of a small coupling 15a. A mounting bracket 15b, is provided as a mounting means for the small motor 15, on the front end cap 7, using conventional hardware. The small motor 15, is connected to the vehicle's primary battery, with a dashboard switch,—controlling the starting and stopping of the small motor 15.

A small rectangular funnel-like air scoop 16, is also mounted to the front end cap 7, and is provided with mounting flanges 16a, for securing the air scoop 16, to the front and cap 7, with conventional hardware. An air inlet port 17, within the front air cap 7, is located at the converging base 16b, of the air scoop 16.

The air inlet port 17, is normally kept closed by a sliding, pivoting gate 18, secured by a pivot pin 18a, to the front end cap 7, the pivoting gate 18, slides on the front surface of the front end cap 7, with an extension arm 18b, connected to a clutch arm 19a of a small friction clutch 19, mounted over the front central shaft 12, protrusion. A small tension spring 19b, keeps tension on the clutch arm 19a, against the direction of rotation of the small D.C. motor 15, so that the pivoting gate 18, is normally kept closed.

The small friction clutch 19, is closely fitted on to the front central shaft 12, protrusion through the front end cap 7, so that the clutch arm 18a, will rotate to open the pivoting gate when the small motor 15, runs.

A small diameter tubing connection 20, conveying a small flow of exhaust gases from the rear of the exhaust manifold(s), is connected to the front end cap 7a, by means of threaded connectors at both ends of the tubing 20.

Approximately three conveyor fans 21, are located directly behind the spider support 13, and are secured to a rear central shaft 22, which protrudes through the rear end cap 7a.

A small 12 volt D.C. motor 23 is connected to the rear central shaft 22, by means of a small coupling 23a. A mounting bracket 24, is provided as a mounting means for the small motor 23, on to the rear end cap 7a, using conventional hardware.

The small D.C. motor 23, is connected to the vehicle's primary battery, and to the ignition switch so that the conveyor fans are in immediate operation when the vehicle's engine is running. A medium mesh disc screen 25, is positioned directly behind the rear-most conveyor fan 21, to form the front entrance surface for the final steam reforming stage of the process. A clearance hole 25a, is centrally located within the disc screen 25, to clear the rear central shaft 22.

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A clearance tube 26, is centrally located over the rear central shaft 22, and is secured to the inside face of the rear end cap 7a, by means of the base flanges 26a, and conventional hardware.

A ball or sleeve bearing 14, is positioned within the rear end cap 7a, to support the rear central shaft 22, along with a similar spider support 13, and bearing 14, in front of the forward-most conveyor fan 21, and behind the first wire brush assembly 11.

The disc screen 25, is secured to the front end of the clearance tube 26, so that a hollow cylindrical compartment is formed for the rear steel wool pack 27. The steel wool pack, 27, is closely packed into this compartment in a random manner with the pack 27, retained within the rear section of the reactor cylinder(s) 2, by the rear end cap 7a.

An exit port 28, is located off-center in the rear end cap 7a, to convey the reformed hydrogen gas to the engine's intake manifold 29, through the flexible tubing line 30, from the rear port exit 28, and the threaded connector 30a.

Multiple resistance heaters 31, with threaded bases 31a, are uniformly located and secured to the reactor cylinder(s) 2, to provide the addition heating level required by this process for automotive applications. All of the multiple resistance heaters 31, are connected to the vehicle's second battery 32, to relieve this extra load from the vehicle's primary battery. The electrical resistance heaters 31, are also connected to the vehicle's ignition circuit so that they are actuated when the vehicle's engine is started and running.

Several electrical generating means must be included in the system to recharge the second battery 32, which consist of multiple thermoelectric cells 33, closely mounted on to the engine exhaust pipes 34, by means of adjustable clamps 33a.

Multiple photovoltaic cells 35, would provide another electrical source with these mounted on portions of the vehicle's roof.

Multiple small air-driven disc/generators 36, will be mounted under the vehicle's front hood to provide a small wattage recharging current to the second battery 32. The air-driven discs consist of thin, flat metal discs 36a, with multiple radial vanes 36b, pitched to receive the incoming air flow under the hood caused by the vehicle's forward motion. The air-driven discs 36a, will be mounted on the shaft of a standard electric small dynamo/generator 36b, with the wattage produced by these components small, but steady and in proportion to the vehicle's forward speed.

A small gear reduction unit,—may be required for the small, front 12 volt D.C. motor 15, which drives the front central shaft 12, and the multiple brushes 11, due to the total frictional resistance of all the brushes 11, in rubbing contact with the inside diameter of the reactor cylinder(s) 2.

A series of about three or four internal tiny ribs or fins 37, 37, on the inside diameter of the reactor cylinder(s) 2, which form long, low protrusions parallel to the shaft axis may be necessary as a jogging or shaking means for the multiple wire brushes 11, to remove rust and carbon accumulations.

A variation on the preferred unit(s) design could consist of manual, cable control opening of the front air inlet gate 18, and the elimination of the automatic friction clutch 19, arrangement previously described. The control cable would terminate at a knob control on the vehicle's dashboard which would be actuated when the

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front motor switch 15b, is switched on. This manual control would be adopted if the automatic clutch 19, arrangement should prove troublesome and unreliable.

What is claimed is:

1. A manifold hydrogen generator unit for automotive I.C. engines comprised of a cylindrical iron reactor indirectly attached to the existing exhaust manifold of automotive I.C. engines,

adapter mounting means permanently fastened to said cylindrical iron reactor and adjustable clamping means for said adapter mounting means on to said existing exhaust manifold,

two nearly identical front and rear end caps threaded on to said cylindrical iron reactor,

multiple turns of small diameter metal tubing closely wound longitudinally around and in full contact with said adapter mounting means and said existing exhaust manifold,

plastic water reservoirs uniformly disposed in a raised position above the engine compartment of a motor vehicle,

plastic tubing connection means between said plastic water reservoirs and the rear entrance end of said multiple turns of small diameter metal tubing,

the front steam exit end of said multiple turns of small diameter metal tubing is routed to the front end cap threaded on to said cylindrical iron reactor, threaded connector means for securing said small diameter metal tubing to said front end cap,

multiple uniformly spaced rotary iron wire brushes closely fitted in light rubbing contact with the inside diameter of said cylindrical iron reactor,

said multiple uniformly spaced rotary iron wire brushes all secured to a front central shaft supported by said front end cap and an internal support spider within said cylindrical iron reactor, low friction bearing means centrally disposed within said front end cap and said internal support spider for said front central shaft,

two identical hub discs hold each of said rotary iron wire brushes in a uniformly dense radial pattern,

a major threaded portion disposed on said front central shaft for the securing of each said multiple uniformly spaced rotary iron wire brushes, twin locknuts disposed on either side of each of said two identical hub discs,

a small D.C. electric motor disposed at the front of said front end cap connected to said front central shaft by means of a locking coupling, a mounting bracket for securing said small D.C. electric motor to said front end cap, standard hardware means for fastening said mounting bracket and said small D.C. electric motor,

an air inlet port axially disposed within said front end cap, a rectangular air scoop located over said air inlet port and secured to said front end cap by means of standard hardware through flanges on said rectangular air scoop,

a pivoting metal flap covering said air inlet port disposed in normally closed position over said air inlet port, an arm on said pivoting metal flap connected to an arm on a central friction clutch,

spring means on said arms to maintain said pivoting metal flap in a normally closed position over said air inlet port,

said central friction clutch disposed over and in rotational friction contact with said front central shaft,

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a small diameter metal tubing connection disposed between the rear upper portion of said existing manifold, and said front end cap, threaded connection means at both ends of said small diameter metal tubing connection,

multiple conveyor fans uniformly disposed within said cylindrical iron reactor directly behind said internal support spider, said multiple conveyor fans fastened to a rear central shaft which protrudes through said rear end cap,

a small D.C. electric motor disposed behind said rear end cap and connected to said rear central shaft by means of a locking coupling, a mounting bracket for securing said small D.C. electric motor to said rear end cap, standard hardware means for fastening said mounting bracket and said small D.C. electric motor,

said rear central shaft is supported by low friction bearings within said rear end cap and a second internal support spider within said cylindrical iron reactor,

a medium mesh disc screen disposed behind the rear most said conveyor fan, a central clearance hole within said medium mesh disc screen to clear said rear central shaft,

a hollow clearance tube centrally located over said rear central shaft and secured to the inside face of said rear end cap, said medium mesh disc screen is secured to the front end of said hollow clearance tube,

a fine mesh steel wool pack is placed in the rear compartment formed by the medium mesh disc screen within the cylindrical iron reactor and the inside face of said rear end cap,

an exit port axially disposed within said rear end cap connected by a metal tubing line on the intake manifold of said automotive I.C. engine, threaded connection means at both ends of said metal tubing line,

multiple resistance electrical heaters with threaded bases uniformly disposed and secured into said cylindrical iron reactor, all of said multiple resistance electrical heaters are connected to a second electrical storage battery within the automotive vehicle,

several electrical generating means are included within the automotive vehicle as a recharging means for said second electrical storage battery.

2. A manifold hydrogen generator unit according to claim 1, in

which said cylindrical iron reactor consists of standard iron pipe with an inside diameter of between two and three inches and a length of between sixteen and twenty inches,

the inside diameter of said cylindrical iron reactor consisting of standard iron pipe is smooth true and free of burrs and abrasions,

said cylindrical iron reactor consisting of standard iron pipe is uniformly threaded at both ends and said front and rear end caps have matching threads for connection to said cylindrical iron reactor.

3. A manifold hydrogen generator unit according to claim 1, wherein said small D.C. electric motors are connected to the vehicle's primary electrical battery, connection of one of said small D.C. electric motors disposed on the said front end cap to a switch mounted on the vehicle's dashboard,

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connection of the other said small D.C. electric motor disposed on said rear end cap to the vehicle's ignition switch,

connection of said multiple resistance electrical heaters to the vehicle's ignition switch.

4. A manifold hydrogen generator unit according to claim 1, in which said several electrical generating means for the said second electrical storage battery partially consist of multiple arrays of thermoelectric cells closely secured to the to the engine's exhaust pipes, multiple arrays of silicon photovoltaic cells on portions of the vehicle's roof,

multiple air driven disc/generators uniformly disposed within the vehicle's engine compartment, said multiple air driven disc/generators consist of flat metal discs with multiple cut and pitched vanes, said flat metal discs are fitted and secured to the shafts of small standard electric dynamos running as generators.

5. A manifold hydrogen generator unit according to claim 1, in which multiple turns of small diameter metal tubing is spirally wound around said existing exhaust manifolds,

matching clearance grooves uniformly disposed within said adapter mounting means into which the spirally wound small diameter metal tubing closely fits,

a minimum of six and a maximum of twelve spirally wound tubing loops uniformly disposed around a single exhaust manifold,

a minimum of two and one-half longitudinal tubing loops and a maximum of four and one-half longitudinal tubing loops disposed around said existing exhaust manifolds of an automotive I.C. engine.

6. Manifold hydrogen generator units for automotive I.C. engines comprised of twin cylindrical iron reactors directly attached to existing dual exhaust manifolds of automotive I.C. engines,

adapter mounting means permanently fastened to said twin cylindrical iron reactors,

adjustable clamping means for said twin cylindrical iron reactors and adapting mounting means on to said existing dual exhaust manifolds of automotive I.C. engines,

two identical front and rear end caps threaded on to said twin cylindrical iron reactors,

multiple loops of small diameter metal tubing spirally wound and in full contact with said adapter mounting means and said existing dual manifolds of said automotive I.C. engines,

multiple plastic water reservoirs disposed in a raised position above the engine compartment of a conventional motor vehicle, plastic tubing connection means between said multiple plastic water reservoir's and the rear entrance end of said multiple loops of small diameter metal tubing,

the steam exit end of said multiple loops of small diameter metal tubing is routed around to the front end cap threaded on to said twin cylindrical iron reactors, threaded connector means for securing said small diameter metal tubing to said front end cap,

multiple uniformly spaced rotary iron wire brushes closely fitted in light rubbing contact with the inside diameter of said cylindrical iron reactor, said multiple uniformly spaced rotary iron wire brushes all secured to a front central shaft supported by



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said front end cap and an internal support spider deep within said cylindrical iron reactor,  
 low friction bearing means centrally disposed within said front end cap and said internal support spider for said front central shaft,  
 two identical hub discs securing said rotary iron wire brushes in a uniformly dense radial pattern,  
 twin locking collars disposed on either side of each of said two identical hub discs over said front central shaft,  
 a small D.C. electric motor disposed at the front of said front end cap and connected to said front central shaft by means of a small locking coupling, a mounting bracket for securing said small D.C. electric motor to said front end cap, standard hardware means for fastening said mounting bracket and said small D.C. electric motor,  
 an air inlet port axially disposed within said front end cap, a rectangular air scoop located over said air inlet port and secured to said front end cap by means of standard hardware through flanges on said rectangular air scoop,  
 a pivoting metal flap covering said air inlet port disposed in a normally closed position, an arm on said pivoting metal flap connected to a control cable terminating at a control knob on the automotive vehicle's dashboard,  
 a small diameter metal tubing connection disposed between the rear upper portion of said exhaust manifolds and said front end cap, threaded connection means at both ends of said small diameter tubing connection,  
 multiple conveyor fans uniformly disposed within the rear portion of said cylindrical iron reactors directly behind said internal support spider, said multiple conveyor fans are fastened to a rear central shaft which protrudes through said rear end cap,  
 a small D.C. motor disposed behind said rear end cap and connected to said rear end cap by means of a small locking coupling, a mounting bracket for securing said small D.C. motor to said rear end cap, standard hardware mounting means for fastening said mounting bracket and said small D.C. motor,  
 said rear central shaft is supported by low friction bearings within said rear end cap and an internal support spider within said cylindrical iron reactor,  
 a fine mesh screen disc disposed behind the rearmost said conveyor fan, a central clearance hole disposed within said fine mesh screen disc to clear said rear central shaft,  
 a hollow clearance tube centrally located over said rear central shaft and secured to the inside face of said rear end cap, said fine mesh screen disc is secured to the front end of said hollow clearance tube,  
 a fine mesh steel wool pack is disposed within the rear portion of said cylindrical iron reactor formed by said fine mesh screen disc and the inside face of said rear end cap,  
 an exit port axially disposed within said rear end cap is connected by a metal tubing loop with said automotive I.C. engine's intake manifold, threaded connection means at both ends of said metal tubing loop,  
 multiple resistance electrical heaters with threaded bases uniformly disposed and secured into said cylindrical iron reactors, all of said multiple resistance electrical heaters are connected to a second

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electrical storage battery within the said automotive vehicle,  
 several electrical generating means included within the said automotive vehicle as a recharging means for said second electrical storage battery.  
 7. Manifold hydrogen generator units for for automotive I.C. engines according to claim 6, in which said multiple loops of small diameter tubing spirally wound around said existing exhaust manifolds is formed with a minimum of eight loops and a maximum of twelve loops around a single existing exhaust manifold,  
 matching grooves uniformly disposed within said adapter mounting means into which said spirally wound small diameter tubing closely fits,  
 said multiple loops of small diameter tubing is formed from standard copper tubing.  
 8. Manifold hydrogen generator units for automotive I.C. engines according to claim 6, wherein said twin cylindrical iron reactors are fitted with a longitudinal series of tiny ribs uniformly disposed on the inside diameter,  
 said longitudinal series of tiny ribs are smooth over their entire surfaces and are disposed in the zone of said multiple uniformly spaced rotary iron wire brushes,  
 a minimum of two said longitudinal series of tiny ribs and a maximum of four said longitudinal series of tiny ribs equally spaced around the inside diameter of said cylindrical iron reactors,  
 said twin cylindrical iron reactors consist of standard iron pipe with an inside diameter of between two and four inches and a length of between fifteen and twenty-four inches, the inside diameter of said cylindrical iron reactors consisting of standard iron pipe is smooth and free of burrs and abrasions.  
 9. Manifold hydrogen generator units for automotive I.C. engines according to claim 6, in which said small D.C. electric motor disposed at the front of said front end cap is provided with a small matching gear reduction unit for a torque increase for said front central shaft,  
 said small matching gear reduction unit is mounted to said mounting bracket along with said small D.C. electric motor,  
 connection of said small D.C. electric motors to the vehicle's primary electrical battery,  
 connection of said small D.C. electric motor disposed at the front of said front end cap to an electrical switch mounted on the vehicle's dashboard,  
 connection of the other rear said small D.C. electric motor disposed on said rear end cap to the vehicle's ignition switch,  
 connection of said multiple resistance electrical heaters to the vehicle's ignition switch.  
 10. Manifold hydrogen generator units for automotive I.C. engines according to claim 6, wherein said several electrical generating means for the said second electrical storage battery ery partially consist of multiple arrays of Seebeck effect thermoelectric cells closely attached to the automotive I.C. engine's exhaust pipes,  
 said several electrical generating means for said second electrical storage battery partially consist of multiple arrays of silicon photovoltaic cells or amorphous silicon film uniformly mounted on portions of the vehicle's roof,  
 multiple air driven disc generators uniformly disposed within the vehicle's engine compartment in the zone of the incoming air flow, said multiple air driven disc generators consisting of flat metal discs with multiple cut and pitched vanes.

\* \* \* \* \*

**United States Patent** [19]**Pinto**[11] **4,264,567**[45] **Apr. 28, 1981****[54] METHOD FOR PRODUCING A HYDROGEN-CONTAINING GAS****[75] Inventor:** Alwyn Pinto, Middlesbrough, England**[73] Assignee:** Imperial Chemical Industries Limited, London, England**[21] Appl. No.:** 51,408**[22] Filed:** Jun. 25, 1979**[30] Foreign Application Priority Data**

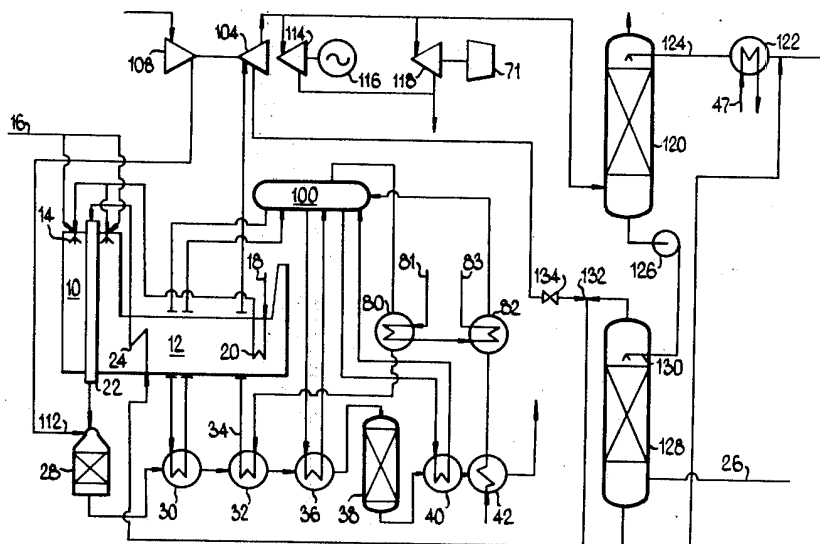
Jul. 7, 1978 [GB] United Kingdom ..... 29230/78

**[51] Int. Cl.:** ..... C01B 1/13; C01C 1/04**[52] U.S. Cl.:** ..... 423/359; 252/373; 423/650**[58] Field of Search** ..... 423/359, 360, 361, 650, 423/651, 652, 653, 654; 48/214 A, 197 R, 213, 215; 252/373, 374**[56] References Cited****U.S. PATENT DOCUMENTS**3,441,393 4/1969 Finneran ..... 423/359  
4,148,866 4/1979 Becker ..... 423/359**FOREIGN PATENT DOCUMENTS**1280226 10/1968 Fed. Rep. of Germany .  
1115100 5/1968 United Kingdom .**OTHER PUBLICATIONS**

Olsen, "Unit Processes and Principles of Chemical Engineering", D. Van Nostrand Co., Inc. (1932), pp. 1-3.

*Primary Examiner*—O. R. Vertiz*Assistant Examiner*—Wayne A. Langel*Attorney, Agent, or Firm*—Cushman, Darby & Cushman**[57]****ABSTRACT**

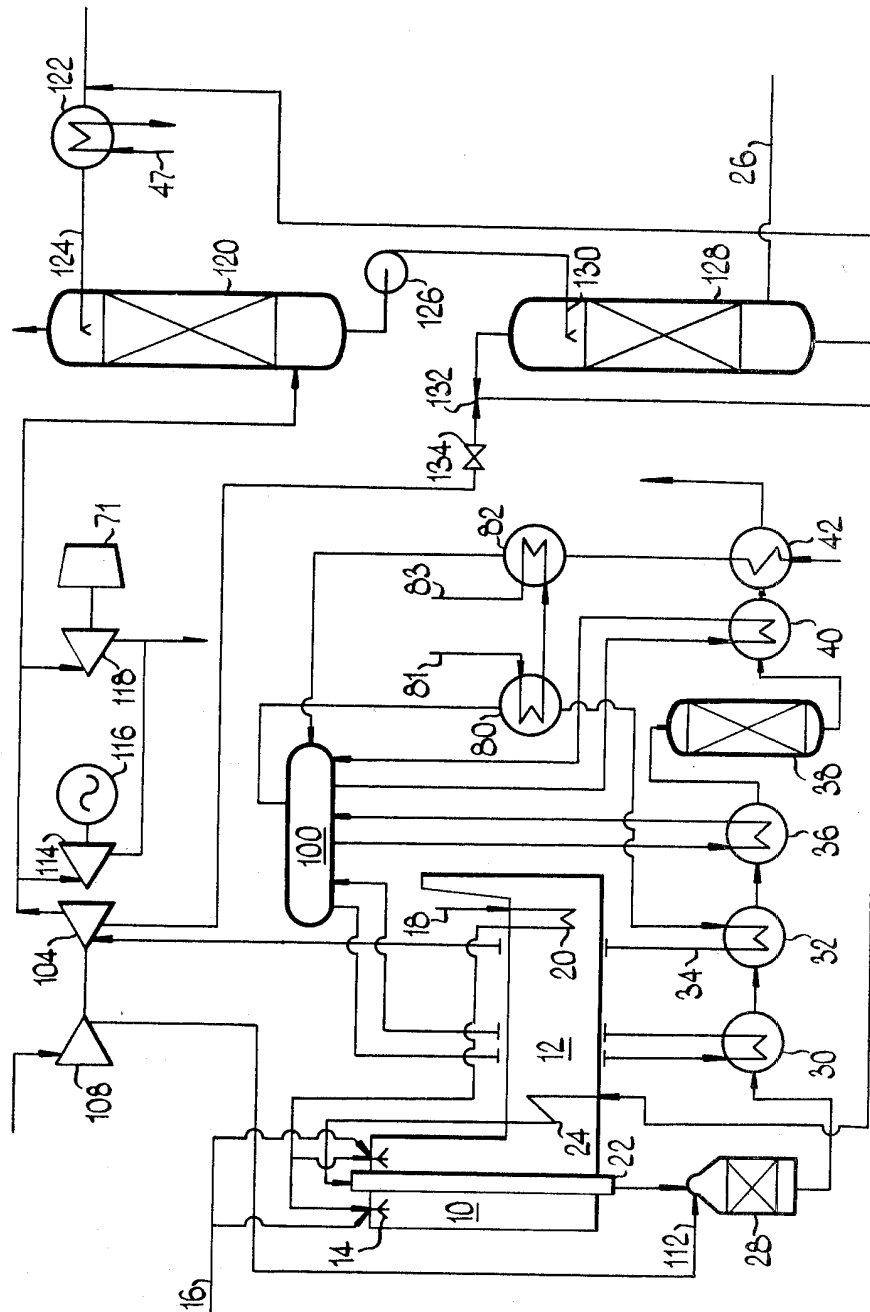
In a process for producing a hydrogen containing gas by reacting steam with a feedstock to give a gas at a temperature of at least 350° C., generating high pressure steam by heat exchange with such a gas, letting down the steam in an expansion engine of the pass-out type and using engine exhaust steam as process feed, an improvement in energy economy is achieved by bringing the engine exhaust steam into heat exchange with water and contacting the resulting hot water with a gaseous or vaporised feed to the process. The steam exhausted from the engine is preferably at a pressure lower than that at which the steam-using process step is generated. The process is especially useful in ammonia production by way of steam hydrocarbon reforming at an unconventionally high pressure in the range 40-80 bar abs, followed by synthesis at a pressure not more than 50% higher.

**8 Claims, 1 Drawing Figure**

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## METHOD FOR PRODUCING A HYDROGEN-CONTAINING GAS

This invention relates to hydrogen and in particular to a process and apparatus for producing a hydrogen-containing gas.

In a widely used process for producing hydrogen or a hydrogen-containing synthesis gas, a carbonaceous feedstock which is carbon monoxide or a gaseous or volatilised hydrocarbon is reacted with steam over a catalyst at an outlet temperature of at least 350° C. and the resulting raw gas is cooled in heat exchange with water to produce steam. If the feedstock is a hydrocarbon the reaction with steam is endothermic and the reaction heat is provided by a combustion furnace, the flue gases of which can be heat-exchanged with water to produce steam instead of or in addition to the steam produced by cooling the raw gas. In the process of this kind described in U.S. Pat. No. 3,441,393 the steam is let down in an expansion engine driving a compressor for one or more of the gas streams in the process and the pressures of steam generation and at the engine outlet are chosen so that (a) the engine provides sufficient power and (b) the outlet steam can be fed to the reaction of the feedstock with steam.

We have realised that whereas the engine power available has been limited by the need to fix the engine outlet pressure at a level above the pressure at the inlet of the feedstock-steam reaction, this can be avoided by adding the steam in a different way. The engine-power limitation is more serious the higher the pressure at which the feedstock-steam reaction is to be operated and can lead to inefficient use of fuel especially in processes in which the raw gas is generated at so high a pressure that little if any compression is applied before (following the usual purification steps) it is used in synthesis, such as of ammonia or methanol. We have realised too that our new process can be used in the framework of gasification of carbonaceous feedstocks by partial oxidation.

According to the invention a process for producing a hydrogen-containing gas by reacting indirectly or directly with steam a carbonaceous feedstock comprises the steps of

- (a) passing a mixture of steam and the feedstock or a steam-reactive derivative thereof through at least one reaction zone and thereby producing at least one gas at a temperature of at least 350° C.;
- (b) generating high pressure steam by heat exchange between water and at least one of the said gases and/or of a gas produced in converting such a feedstock to such a steam-reactive derivative;
- (c) letting down the said steam in an expansion engine of the pass-out type;
- (d) using the engine exhaust steam as part or all of the feed of at least one of the reaction zones of step (a); and is characterised by
  - (i) bringing the engine exhaust steam into heat exchange with water whereby to produce a stream of hot water under pressure; and
  - (ii) contacting the hot water with at least one of the gaseous or vaporised feeds to at least one of the reaction zones of step (a) whereby to provide at least part of the steam requirement of the said zone or zones.

The carbonaceous feedstock can be carbon monoxide or any one of natural gas, gaseous hydrocarbons, volati-

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lisable hydrocarbons, non-volatilisable hydrocarbons and solid materials such as coal, coke, shale and waste materials.

By "direct reaction" with steam is meant a process in which the starting feedstock is converted to a gas by reaction with at least sufficient steam to complete the conversion to its equilibrium state. Direct reaction is practised using only the first 4 feedstocks mentioned. By "indirect reaction" is meant the process sequence (such as those based on the gas recycle hydrogenator GRH or fluidised bed hydrogenator FBH) in which the feedstock is first either hydrogenated to hydrocarbons, especially methane, or else partially oxidised to produce a gas containing carbon monoxide; thereafter the hydrocarbon or carbon monoxide is reacted directly with steam. Such hydrocarbon or carbon monoxide is a "steam-reactive derivative" of the starting feedstock. The partial oxidation is commonly carried out in the presence of a small proportion of steam, too little to react with all the carbon monoxide formed. The indirect reaction with steam is less commonly practised for the gaseous or volatilisable hydrocarbons. The direct reaction of hydrocarbons usually produces a gas at or near chemical equilibrium at a temperature in the range 600°-1100° C., at which a considerable concentration of carbon monoxide, for example 10-40% v/v on a dry basis, is present. In order to increase the proportion of hydrogen this gas is subjected to the shift reaction, similarly to what is used if carbon monoxide is the starting material.

The direct reaction can be carried out in a single stage or a plurality of stages. The single stage can be for example

- A. externally heated "primary" catalytic reforming with steam and/or carbon dioxide, using catalyst in externally heated tubes or in adiabatic beds preceded by heat exchangers;
- B. catalytic partial oxidation in the presence of at least stoichiometric steam in an adiabatic bed;
- C. the shift reaction, when carbon monoxide is available as a starting feedstock.

Plural stage reaction can be for example

- D. A operated so as to produce a gas containing 1-50 especially 2-25% v/v methane on a dry basis, and followed by B ("secondary reforming"), in which the methane content is decreased;
- E. B operated in a first stage to produce a methane-containing gas and followed by a second state of B in which the methane content is decreased;
- F. Adiabatic reaction with steam over a catalyst at an outlet temperature in the range 200°-650° C., especially 350°-550° C., of a vaporised hydrocarbon of higher molecular weight than methane, to give a gas containing suitably 30-70% of methane, on a dry basis, followed by any one of A, B and D, most conveniently A or D.

The reactants and conditions in step (a) are chosen according to the intended composition of the hydrogen-containing gas. Particular examples are:

ammonia synthesis gas:

D or E, with the partial oxidation stage fed with air, in order to introduce nitrogen, and followed by a shift stage;

A or B, followed by addition of nitrogen from an external source and including a shift stage;

methanol synthesis gas:

A without shift, using steam or steam + carbon dioxide;

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D with the partial oxidation stage fed with oxygen, or with air if both ammonia and methanol are to be produced;

F with A as second stage.

high CO gas for various synthesis:

A without shift using steam + carbon dioxide; hydrogen:

A or B with shift.

In more complicated plants more than one of such stages are operated in parallel and their product gases mixed.

When the direct reaction involves the reaction of a hydrocarbon over a catalyst, as in A, B, D, E or F, the hydrocarbon is usually and preferably desulphurised before the reaction, in order to avoid catalyst poisoning. As a result, the product gas can be passed to a shift stage, if required, without further purification. Cooling to shift inlet temperature can include a boiler raising high pressure steam as in step (b).

The indirect reaction via partial oxidation of non-volatilisable feedstocks to produce carbon monoxide necessarily includes a plurality of stages within step (a), but also includes the stages of

cooling and washing to remove ash, carbon and tar;

treating with an absorbent liquid to remove at least

the bulk of the hydrogen sulphide and carbon oxysulphide present.

Such cooling can include a boiler raising high pressure steam as in step (b) for the engine of step (c). After such treatments steam has to be introduced for the shift stage, and according to the invention step (ii) this is done by contacting the treated gas with the hot water produced from the engine pass out steam.

In the indirect reaction via hydrogenation there are corresponding stages for removing gross contaminants and also a stage of fine desulphurisation before the hydrocarbons produced by hydrogenation are passed to the direct reaction using a catalyst. Again the temperature can be high enough to produce high pressure steam.

The hot gases produced in step (a) are one or more of the following:

raw process gas at a temperature in the range 600°–1100° C.;

shifted gas at a temperature in the range 350°–500° C.;

furnace flue gas at a temperature in the range 900°–1400° C.

From any one or more of these high pressure steam (40–200 bar abs.) is generated by heat exchange with boiler feed water. Other heat recoveries that may be operated include preheating reactants for the initial reaction of feedstock with steam or oxygen and superheating steam (which are high grade heat recoveries and are commonly used upstream of the high pressure steam boiler), and also boiler feed water heating, process air heating, furnace combustion air preheating and pressurised hot water heating.

The high pressure steam is generated more preferably at a pressure over 60, especially in the range 80–150 bar abs. The pressure to which such steam is let down in at least one expansion engine is preferably at or less than (preferably by up to 10 bar) the total pressure at the inlet of the stage at which it is to be used. If desired part of the effluent of such an engine can be let down further in one or more second engines exhausting at a still lower pressure or to a condenser. The exhaust of these second engines is preferably used in low grade heating duties. The shaft power generated by the engines, which are

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preferably turbines, can be used, directly or via an electric generator and electric motors, to drive machines forming part of the plant. Such machines include especially

a gas compressor and/or circulator in a high pressure synthesis plant;

an air compressor in a plant involving partial oxidation by air or involving air liquefaction and separation;

a refrigerant compressor in the product separation section of an ammonia production process;

a furnace combustion air fan; and

smaller machines such as feed water pumps, CO<sub>2</sub>-absorption liquor pumps and ammonia liquor pumps.

The engine effluent is brought preferably into direct heat exchange with water. This can be effected for example in a packed column or plate column or by simply injecting water into the flowing steam. The water preferably has been preheated, suitably to a temperature in the range 150° to 250° C., by heat exchange with one or more of the low grade heat sources in the plant for example gas streams at 150°–300° C. or effluent from a low pressure expansion engine.

The resulting hot water can be under a pressure sufficient to flow into contact with the gaseous or vaporised feed to at least one of the reaction stages of step (a) but, in the preferred process in which the steam is expanded to a pressure equal to or less than the reaction stage inlet pressure, it has to be pumped; such pumping of water, however, uses little power. The relevant feed to step (a) can be for example gaseous hydrocarbon, vaporised normally liquid hydrocarbon, methane-containing gas from a preceding stage of hydrocarbon hydrogenation or adiabatic hydrocarbon-steam reaction, carbon monoxide containing gas, carbon dioxide, air or oxygen. Most conveniently it is gaseous or vaporised hydrocarbon to be fed to stage A or stage B as defined above. The feed is preferably at a temperature in the range 20° to 200° C. before contact with the hot water. Contacting can be in for example a packed column or plate column or by spraying the hot water into the flowing feed.

The proportion of steam introduced by such contacting can be 100% of the requirement but is preferably up to 95% for example 30–90%, the remainder being direct steam, in order to facilitate control.

The process is especially advantageous when the pressure at the inlet of the zone or zones fed with a mixture including steam introduced by contacting with hot water is over 10 bar abs., especially in the range 30–150 bar abs. Pressures in that range are well established for non-catalytic partial oxidation processes and the ensuing shift process. It has been proposed in our European published application 993 to operate an endothermic catalytic steam hydrocarbon reforming process at pressures in the range 30–120, especially 40–80 atm. abs. Such a process is very suitably operated according to the invention, whether as part of an ammonia production process as in that application or for other uses.

The following description of shift and carbon oxides removal stages applies specifically to generating ammonia synthesis gas. In generating hydrogen the stages are substantially the same except that usually nitrogen is not present. In generating synthesis gases containing carbon oxides and hydrogen, shift and carbon dioxide removal are used only to the extent required in view of the carbon oxide to hydrogen ratio. In the important case of

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producing methanol synthesis gas by direct catalytic reaction of hydrocarbon boiling at up to 220° C. with steam, no shift or carbon dioxide-removal is needed. In each process sequence there is a stage of steam removal, which may be by indirect cooling and separation or, more preferably, by injection of water; the resulting warm water can be used as feed to step (i).

Since in step (ii) the steam is provided without boiling the water at a heating surface, the water need not be purified to the extent necessary for use in a boiler. Accordingly it can be process condensate from the above-mentioned steam removal or from a subsequent aqueous ammonia distillation or urea synthesis. Any ammonia, methanol, carbamate or urea in such water is decomposed in the chemical reaction steps after formation of the steam-containing mixture.

In a preferred ammonia production process based on a direct steam/hydrocarbon reaction over a catalyst with external heating as A above the pressure at the outlet of that catalyst is preferably in the range 30–120, especially 40–80 bar abs. and the temperature is in the range 750°–850° C. The steam ratio is preferably in the range 2.5–3.5 molecules of total steam per atom of carbon in the hydrocarbon if all the steam and hydrocarbon are fed to this stage. (This steam is fed mainly by contact with the hot water, according to the invention). The methane content of the product gas is typically in the range 10 to 20% by volume on a dry basis and this is preferred, although it is considerably higher than is normally thought suitable in the primary reformer gas of an ammonia synthesis plant. The catalyst is usually refractory-supported nickel.

The primary reformer gas leaving the catalyst may if desired be further heated and then enters the secondary reforming stage, which is a catalytic partial oxidation as B above, where it reacts with an oxygen-containing gas, which is preferably preheated to a temperature in the range 400°–700° C. Further steam can be fed to the secondary reformer or further hydrocarbon feedstock if it is desired to minimise the total steam ratio without having too low a primary reformer steam ratio. (This steam is preferably fed as superheated steam to avoid lowering the temperature). The outlet pressure is about the same as at the outlet of the primary reformer, apart from the pressure drop through the secondary reforming catalyst. The outlet temperature is preferably in the range 950°–1050° C. and the outlet methane content in the range 0.2 to 10% v/v on a dry basis. The proportion of air is preferably such to produce a gas containing 2.0 to 2.9 molecules of hydrogen equivalent (i.e. total of H<sub>2</sub> and CO) per molecule of nitrogen. The catalyst can be for example a supported nickel catalyst or chromium oxide catalyst or a combination thereof. The process in which there is used a quantity of air in excess of what would introduce 1 molecule of nitrogen per 3 molecules is preferably combined, as described in our European published application 993, with the subsequent feature of treating synthesis gas, after reaction to synthesis ammonia, to separate a stream enriched in hydrogen and returning the enriched stream to the synthesis.

By the above-mentioned heat recoveries the gas produced by preceding stages is cooled to a temperature in the range 300°–400° C., especially 320°–350° C., and then, if sufficiently pure, is passed to an iron-chrome shift catalyst. The reaction over the iron-chrome catalyst is exothermic (outlet temperature 400°–450° C.) and the outlet gas is again cooled with recovery of useful heat (including high pressure steam) in a similar manner

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to the cooling of process gas from earlier stages. It is then subjected to further shift reaction, preferably over a copper-containing catalyst, for which the inlet temperature is suitably 200°–240° C. and the outlet temperature 240°–270° C. Such a low-temperature shift stage produces a gas containing usually 0.1 to 0.6% v/v of carbon monoxide on a dry basis. When as is preferred, the pressure is higher than has been generally used in low temperature shift, the steam to dry gas ratio over the low temperature shift catalyst is kept down to a level that avoids damage to the catalyst, preferably in the range 0.1 to 0.3. This means that the steam to carbon ratio in any preceding steam/hydrocarbon reaction stages should not be too high, but it can be readily attained using ratios initially in the range 2.5 to 3.5 (methane feedstock) or 2.4 to 3.2 (feedstock of empirical formula CH<sub>2</sub>) or in intermediate ranges for hydrocarbons of intermediate composition. The higher nitrogen content due to excess air helps to keep down the steam to dry gas ratio. If it is desired to use a higher steam to carbon ratio in preceding stages, or to add extra steam in shift stages, the steam to dry gas ratio can be kept down by recycling gas from positions downstream of carbon dioxide removal. Alternatively two or more high temperature shift stages separated by carbon dioxide removal can be used.

The outlet temperature of the low temperature shift stage is too low to produce high pressure steam, but useful heat can be recovered from the shifted gas in lower grade heat recoveries such as water heating for boiler feed or step (ii) and feedstock heating in series or parallel with the recoveries from the hotter gases already described and also such as carbon dioxide removal solution regeneration and aqueous ammonia distillation.

If the gas from the preceding stages contains sulphur it can be shifted non-catalytically or over a catalyst containing compounds of Group VI and Group VIII metals other than chromium and iron or containing alkali metal compounds of weak acids. Analogous heat recoveries are effected.

In producing pure hydrogen or ammonia synthesis gas, removal of carbon oxides is usually carried out in a first stage in which carbon dioxide is substantially removed, and a second in which carbon oxides removal is substantially complete such that catalysts such as ammonia synthesis catalyst are not significantly poisoned by them. If desired, carbon monoxide remaining after shift can be selectively oxidised to carbon dioxide, which is then removed along with carbon dioxide previously present. For the first removal stage the process gas is cooled, water is separated, suitably by direct contacting with added water to produce a feed for step (i), and then the first stage can be carried out using any liquid absorbent. Well-established chemical systems such as Benfield's potassium carbonate or diethanolamine potassium carbonate, "Vetrocoke", "Catacarb" or amine systems such as monoethanolamine can be used. These have, however, the disadvantage of consuming a substantial quantity of steam in the regeneration of the liquid absorbent, a requirement that is especially inconvenient when the steam to dry gas ratio of the shifted gas is at the preferred low levels. A 2-stage carbon dioxide removal, in the first stage of which most of the carbon dioxide is absorbed in an amine, such as triethanolamine, that is regenerable substantially without heating, and only in the second stage of which an absorbent is used that does require heat regeneration, is

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therefore preferable. The preferred high pressure makes possible the use of "physical" absorbents, the preferred examples of which can be regenerated merely by lowering pressure. Suitable absorbents used in industrially developed processes are tetramethylene sulfone ("Sulfinol"), propylene carbonate (Fluor), N-methyl-2-pyrrolidone ("Purisol"), methanol ("Rectisol") and the dimethyl ether of polyethyleneglycol ("Selexol").

If desired, part or all the carbon dioxide can be removed by absorption in anhydrous or aqueous ammonia. Such a procedure is especially useful if the ammonia is to be used for urea synthesis or for making ammonium sulphate by the calcium sulphate process. In a convenient form of the process, applicable especially when it is desired to operate at pressures less than optimal for using physical absorbents, the bulk of the carbon dioxide can be removed in a physical absorbent and the remainder in a chemical solvent as mentioned above or in ammonia. The latter procedure can be designed to suit any desired relative outputs of ammonia, carbon dioxide and urea.

The second stage of carbon oxides removal can be carried out by cryogenic separation or by contacting the gas with a carbon oxides absorbent such as copper liquor, but is most conveniently effected by catalytic methanation, for example over a supported nickel catalyst at an outlet temperature in the range 250°–400° C. This decreases the carbon oxides content to a few parts per million by volume but produces water, which can be removed by cooling, separation and passage over a water-absorbent such as alumina or a molecular sieve. The second stage can not be effected by means of liquid nitrogen washing, which can introduce nitrogen if required.

In a preferred ammonia production process according to the invention the dried gas contains nitrogen, hydrogen preferably in less than the stoichiometric ratio for ammonia synthesis, a small quantity of methane and fractional percentages of noble gases introduced with the secondary reformer air, and is thus ready for use as an ammonia synthesis gas. It may be compressed to any convenient synthesis pressure, but at the high pressure preferred for step (a) it is suitable for use in the synthesis with less than 50% compression and preferably no more than the increase in pressure (for example up to 20%) encountered in a synthesis gas circulator. If compression is used, it is preferably by up to 100 bar, conveniently in the range 20–80 bar, so that a single-barrel compressor-circulator can be used.

The "fresh" synthesis gas can be fed through a succession of catalytic stages and ammonia removal stages but, as in most ammonia synthesis processes, is preferably mixed with synthesis gas recycled from an ammonia removal stage. At the preferred synthesis pressures the attainable pass conversion over the synthesis catalyst is relatively low, giving an ammonia outlet concentration in the range 8 to 12% v/v. The ratio of recycled gas to fresh gas is suitable in the range 4 to 6.

The catalyst used in the ammonia synthesis can be of the usual composition, namely iron with promoting quantities of nonreducible oxides such as those of potassium, calcium, aluminium and others such as of beryllium, cerium or silicon. In order to afford maximum activity and thus to compensate for the lower rate of reaction due to low pressure, the iron catalyst preferably contains also cobalt, suitably to the extent of 1–20% w/w calculated as  $\text{Co}_3\text{O}_4$  on the total oxidic composition from which the catalyst is made by reduction and in

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which the iron oxide is assumed to be all  $\text{Fe}_3\text{O}_4$ . The catalyst can be in the form of particles in the sieve range 18 to 4 ASTM (1–4.7 mm) especially 10 to 5 (2–4 mm), if it is desired to maximise their available contact surface or larger, for example up to 20 mm; the arrangement of the catalyst in the synthesis reactor preferably therefore may afford short gas flow paths, such as by radial or secantial flow in a cylindrical reactor. The outlet temperature of the synthesis catalyst is preferably in the range up to 500° C., especially 350°–430° C. This is lower than has been usual, in order to obtain a more favourable synthesis equilibrium. The catalyst volume is suitable in the range 100–200  $\text{m}^3$  per 100 metric tons per day output; this is higher than has been usual but can be tolerated because at the low operating temperature and pressure the reactor can be of simple construction for example of the hot-wall type.

Reacted gas can be cooled during, between stages of or after the synthesis, by any convenient means, but according to the invention the hot gas at some point is heat exchanged with high pressure steam generated by cooling furnace flue gas or step (a) process gas or high temperature shift outlet gas, or with intermediate pressure steam exhausted from a pass-out turbine or generated independently. Preferably the steam is heat exchanged with reacted synthesis gas leaving one, preferably the first, of a succession of catalyst beds, and preferably before the reacted gas has been cooled in any other heat exchange. The heat exchange with steam is preferably followed by heat exchange with feed water for the boilers of step (b) and these two heat exchangers are operated preferably so as to cool the reacted synthesis gas from one catalyst bed to the temperature at which they are to enter the next bed. After the gas has left all the catalyst beds or parts thereof it is cooled by heat exchange with incoming unreacted synthesis gas and with boiler feed water, each in one or more stages and in any convenient order, and then finally cooled to ammonia separation temperature.

The recovery of ammonia from reacted synthesis gas can be carried out by ordinary air-cooling or water-cooling if the pressure is high enough, but at preferred pressures in the range 40–80 bar. abs. is best carried out by absorption in water. Absorption in an acid or on a solid such as zinc chloride can be used if convenient. Absorption in water is conveniently carried out in two or more stages, for example in the first of which the gas contacts a relatively strong ammonia solution (for example 15 to 30% w/w) and in the last pure water or a weak ammonia solution (for example up to 10% w/w). After the absorption stage the gas is dried in order to prevent too-rapid deactivation of the catalyst by water. The aqueous ammonia product can be used as such or distilled to recover anhydrous ammonia from it.

When the fresh synthesis gas contains nitrogen in excess, noble gases and methane, continued removal of ammonia from it, especially in a recycle process, results in a substantial concentration of non-reacting gases. It is preferred to treat the gas mixture to keep the concentration of such gases below 10 especially below 5.0% v/v. This treatment could be applied to the fresh or mixed synthesis gas before entering the synthesis or to the whole of the reacted gas after removal of ammonia, but it is preferred to apply it only to a side stream, because then any failure of the treatment plant does not cause a shut-down of the whole production process. The side stream can conveniently be taken from the gas downstream of the ammonia separation and treated for hy-

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drogen separation, whereafter the hydrogen is returned to the circulating synthesis gas. It could in principle be taken before ammonia separation but the treatment would then involve also a substantial ammonia recovery. The hydrogen separation treatment involves a pressure-drop and may involve also a pressure let-down through an expansion engine in order to decrease the gas temperature for cryogenic separation; consequently the hydrogen stream has to be compressed in order to return it to the synthesis. Preferably therefore the side stream is taken from the effluent of the circulator, where the gas pressure in the system is highest, and the separated hydrogen stream is returned to the inlet of the circulator, where the gas pressure is lowest. Part or all of the separated hydrogen stream can be recycled to the low temperature shift inlet.

The hydrogen separation treatment can be by any suitable means, for example by cryogenic fractionation, molecular sieve adsorption or palladium membrane diffusion.

The plant in which the process of the invention takes place is a new combination and constitutes a further feature of the invention.

The drawing, a flowsheet of one preferred form of the invention, shows the major chemical processing steps and heat exchanges in the synthesis gas generation section of an ammonia production process.

The process is based on steam-natural gas reforming. The reforming furnace has a radiative zone 10 and a convective zone 12. Zone 10 is heated by burners 14 fed with preheated natural gas from 16 and air fed in at 18 and preheated at 20 at the low temperature end of convective zone 12. The catalyst tubes 22 heated in radiative zone 10 are fed with a steam/natural gas mixture strongly preheated at 24 in the hottest part of convection zone 12. The mixture is formed in tower 128 from warm natural gas fed at 26 from a desulphurisation plant (not shown) and hot water fed over the packing of the tower at 130 and with the addition of a small quantity of steam at 132. The source of the hot water and steam will be described below. Gas leaving tube 22 consists of carbon oxides, hydrogen and methane. It is partly burnt with hot air supplied at 112 (from compressor 108 which has no final cooling stage and thus supplies hot air needing no preheating) at the inlet of secondary reformer 28 and then brought to equilibrium at a lower methane content over the secondary reformer catalyst. The gas leaving secondary reformer 28 is cooled in boiler 30 feeding high pressure steam drum 100, then cooled further in the heat exchanger 32 (a steam superheater feeding steam through line 34 to turbine 104) and boiler 36 also feeding steam drum 100. At the temperature of inlet to high temperature shift catalyst it now enters reactor 38 in which carbon monoxide reacts with steam to give carbon dioxide and hydrogen. This reaction is exothermic and the hot reacted gas is cooled in heat exchanger 40 (a boiler feeding steam drum 100) and 42 (a boiler feed water heater) to the inlet temperature of the low temperature shift catalyst. (The subsequent stages of low temperature shift, steam separation by direct or indirect heat exchange with water, carbon dioxide absorption, methanation and ammonia synthesis do not affect the principle of the invention and are not shown, except in so far as heat is derived from them in exchangers 80, 82 and 122).

The steam system that characterises the process according to the invention is based, in this preferred flowsheet, on common steam drum 100. Drum 100 is fed

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with treated boiler water heated in exchanger 82 by reacted ammonia synthesis gas that has been partly cooled in superheater 80 and is now led back to the synthesis through line 83: the feed to exchanger 82 is already warm as a result of low grade heat recoveries such as 42 and other positions not shown such as possibly after low temperature shift and in convective zone 12 of the steam reforming furnace. Water circulates from drum 100 through boilers 30, 36 and 40 already described. Steam passing overhead from drum 100 is superheated in heat exchanger 80 by reacted ammonia synthesis gas led in by line 81 from the synthesis catalyst, superheated further by hot raw synthesis gas at 32 and let-down in high pressure pass-out turbine 104 driving process air compressor 108, which supplies hot air to secondary reformer 28 at point 112. A small quantity of steam is exhausted at a pressure above the inlet pressure of reformer tube 22 and fed into the natural gas steam flow via valve 134 to be described. The main exhaust is at a pressure lower than the inlet of tube 22 and is divided into three part streams. The first feeds turbine 114, which drives alternator 116 supplying electricity to the small machines of the plant. The second part stream feeds turbine 118, which drives circulator 71 in the ammonia synthesis loop. (As a result of the high synthesis gas generation pressure there is no synthesis gas compressor). Turbines 114 and 118 are both of the pass-out type. Their exhaust steam is used in low-grade heating duties, principally the distillation of aqueous ammonia. In such duties it is condensed and may be recovered and used as boiler feed water (after de-aeration) or as warm water to be used in tower 120.

The third part stream is fed to packed tower 120. Here it flows upwards through the packing countercurrent to a flow of warm water fed in at 124. The water has been warmed at 122 in heat exchange with low temperature shift effluent gas fed in at 47. (As an alternative, heat exchanger 122 could be a packed tower in which warm water contacts such shift effluent gas directly and removes steam from it). Tower 120 includes an overhead valve for venting any gases introduced with the steam and water.

The bottoms liquid of tower 120 is hot water carrying the sensible heat of the warm water fed in at 124 and both the sensible and latent heat of the steam fed in from turbine 104. It is propelled by pump 126 into the top of packed tower 128 and therein flows downwardly countercurrent to a stream of warm desulphurised natural gas fed in at 26. Water in at 26. Water evaporates and the resulting saturated natural gas passes overhead to mixing point 132 where there is added a feed of steam under the control of valve 134. The proportion of steam added via valve 134 is typically 10% of the total requirement. The steam/natural gas mixture is now fed to preheater 24 and thence tube 22, as previously described. In tower 128 not all the water evaporates and the remaining liquid is recycled to tower 120 via heat exchanger 122.

In a typical process producing raw synthesis gas for ammonia or methanol synthesis, by endothermic steam reforming of natural gas (stage A above) at 21 bar abs. pressure, steam is generated at 60 bar abs. pressure and let down in an expansion engine. For an hourly output of 41.7 metric tons of ammonia the steam output is 248 metric tons per hour. This steam is let down in an expansion engine exhausting in part at 28, in part at 19.1 bar abs. The steam at 19.1 bar abs. at the rate of 29 t h<sup>-1</sup>, is condensed into water in tower 120 to give 38850



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kg mol h<sup>-1</sup> of water at 210° C. This water is contacted in tower 128 at 26.1 bar abs. with natural gas (3437.3 kg mol h<sup>-1</sup>, initially at 100° C.) and produces a mixed gas stream containing 4481.7 kg mol h<sup>-1</sup> of steam, at a temperature of 197.9° C. The water discharged from tower 128 (34368.3 kg mol h<sup>-1</sup>) is at 148.7° C. Inert gases (10.9 kg mol h<sup>-1</sup>) are vented from the top of tower 120. Of the steam at 28 bar abs. leaving the engine, 49 te h<sup>-1</sup> are fed into the humidified natural gas stream at point 132. Thus 37.4% of the reactant steam is provided by steam at less than the reformer inlet pressure.

In a corresponding process in which all 78 te h<sup>-1</sup> of reactant steam are fed as steam at 28 bar abs. the steam generation rate has to be 250 te h<sup>-1</sup> and the energy input per te of ammonia produced is greater by 2.0 therms.

In processes in which the primary reformer pressure is higher, for example 40–80 bar abs., the energy saving due to the invention is substantially greater.

I claim:

1. A process for producing a hydrogen-containing gas by reacting indirectly or directly with steam a carbonaceous feedstock which comprises the steps of

- (a) passing a mixture of steam and the feedstock or a steam-reactive derivative thereof through at least one reaction zone and thereby producing at least one gas at a temperature of at least 350° C., said feedstock or steam-reactive derivative thereof being in gaseous or vaporized form;
  - (b) generating high pressure steam by heat exchange between water and at least one of the said gases and/or of a gas produced in converting such a feedstock to such a steam-reactive derivative;
  - (c) letting down the said high pressure steam in an expansion engine of the pass-out type;
  - (d) using the engine exhaust steam as at least part of the steam feed to at least one of the reaction zones of step (a);
- and is characterised by
- (i) bringing the engine exhaust steam into heat exchange with water whereby to produce a stream of hot water under pressure; and
  - (ii) contacting the hot water with at least one of the said feedstock or steam reactive derivative thereof to be fed to at least one of the reaction zones of step (a) whereby to provide at least part of the steam requirement of the said zone or zones.

2. A process according to claim 1 in which in step (c) the pressure to which the steam is let down in at least one expansion engine is at or less than the total pressure at the inlet of the reaction zone of step (a) in which it is to be used, and the resulting engine exhaust steam is fed to the heat exchange in step (i).

3. A process according to claim 1 in which the heat exchange of steam with water in step (i) is direct.

4. A process according to claim 1 in which in step (ii) the hot water is contacted with a gaseous or vaporised

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hydrocarbon to be fed to a stage of externally heated catalytic reforming with steam and/or carbon dioxide or of catalytic partial oxidation in an adiabatic bed.

5. A process according to claim 1 in which 30–90% of the steam requirement of the said zone or zones is provided by contacting with hot water in step (ii).

6. A process according to claim 1 in which the pressure at the inlet of the said zone or zones fed with a mixture including steam introduced by contacting with hot water is in the range 30–120 bar abs.

7. In an ammonia production process which comprises

- (a) primary catalytically reforming at superatmospheric pressure a hydrocarbon feedstock with steam in at least one reaction zone to give a gas containing carbon oxides, hydrogen and methane;
  - (b) secondary catalytically reforming the resulting primary reformer gas by introducing air and bringing the mixture towards equilibrium, whereby to produce a secondary reformer gas containing nitrogen, carbon oxides, hydrogen and a decreased quantity of methane;
  - (c) converting carbon monoxide catalytically with steam to produce a shifted gas containing carbon dioxide and hydrogen; and
  - (d) removing carbon oxides and steam from the shifted gas to give a nitrogen-hydrogen ammonia synthesis gas; and thereafter
  - (e) reacting the synthesis gas to produce ammonia and recovering ammonia from the reacted gas;
- and in which energy is recovered by generating high pressure steam by heat exchange between water and at least one of the said gases containing carbon dioxide and/or flue gas from the furnace used in said primary reforming step, the temperature of such gas before such heat exchange being at least 350° C.;
- letting down the said high pressure steam in an expansion engine of the pass-out type, said engine powering a compressor compressing said synthesis gas preparatory to said synthesis; and using the engine exhaust steam as at least part of the steam feed to said primary reforming step;

the steps of

- (i) bringing the engine exhaust steam into heat exchange with water whereby to produce a stream of hot water under pressure; and
- (ii) contacting the hot water with at least one of the gaseous or vaporised feeds to at least one of the reaction zones of step (a) whereby to provide at least part of the steam requirement of the said zone or zones.

8. A process according to claim 7 characterised further by operating said reforming conversion and carbon dioxide removal steps at a pressure in the range 40–80 bar abs. and increasing the pressure of the resulting ammonia synthesis gas by less than 50% before feeding it to ammonia synthesis.

\* \* \* \* \*

**United States Patent** [19][11] **4,328,768****Tracy et al.**[45] **May 11, 1982****[54] HYDROGEN FUEL STORAGE AND DELIVERY SYSTEM****[75] Inventors:** Joseph C. Tracy, Romeo; Jan F. Herbst, Utica, both of Mich.**[73] Assignee:** General Motors Corporation, Detroit, Mich.**[21] Appl. No.:** 171,753**[22] Filed:** Jul. 24, 1980**[51] Int. Cl.<sup>3</sup>** ..... F02M 31/00; B01D 59/10**[52] U.S. Cl.** ..... 123/1 A; 123/DIG. 12; 55/16; 55/158**[58] Field of Search** ..... 123/1 A, DIG. 12, 23, 123/24; 55/16, 68, 158**[56] References Cited****U.S. PATENT DOCUMENTS**

3,019,853	2/1962	Kohman	55/16
3,100,868	8/1963	McAfee	55/16
3,184,899	5/1965	Frazier	55/16

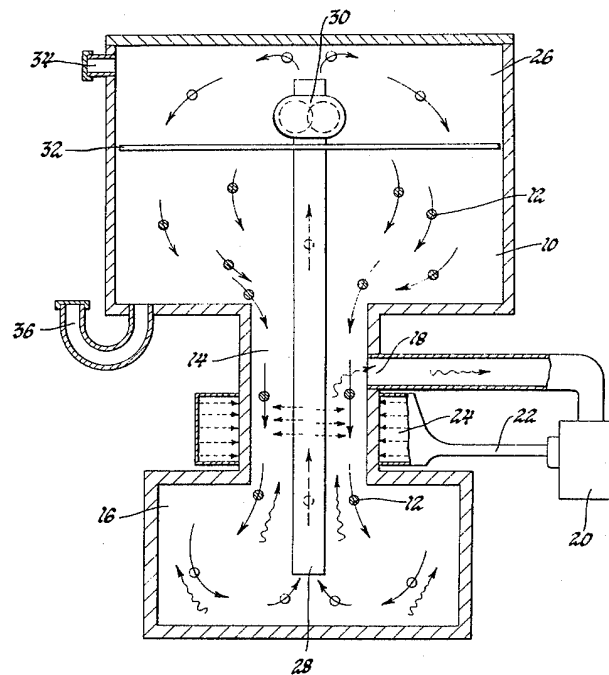
3,262,251 7/1966 Hicks ..... 55/158

**FOREIGN PATENT DOCUMENTS**

1439440 6/1976 United Kingdom ..... 123/1 A

*Primary Examiner*—Ronald H. Lazarus*Attorney, Agent, or Firm*—Donald F. Scherer**[57] ABSTRACT**

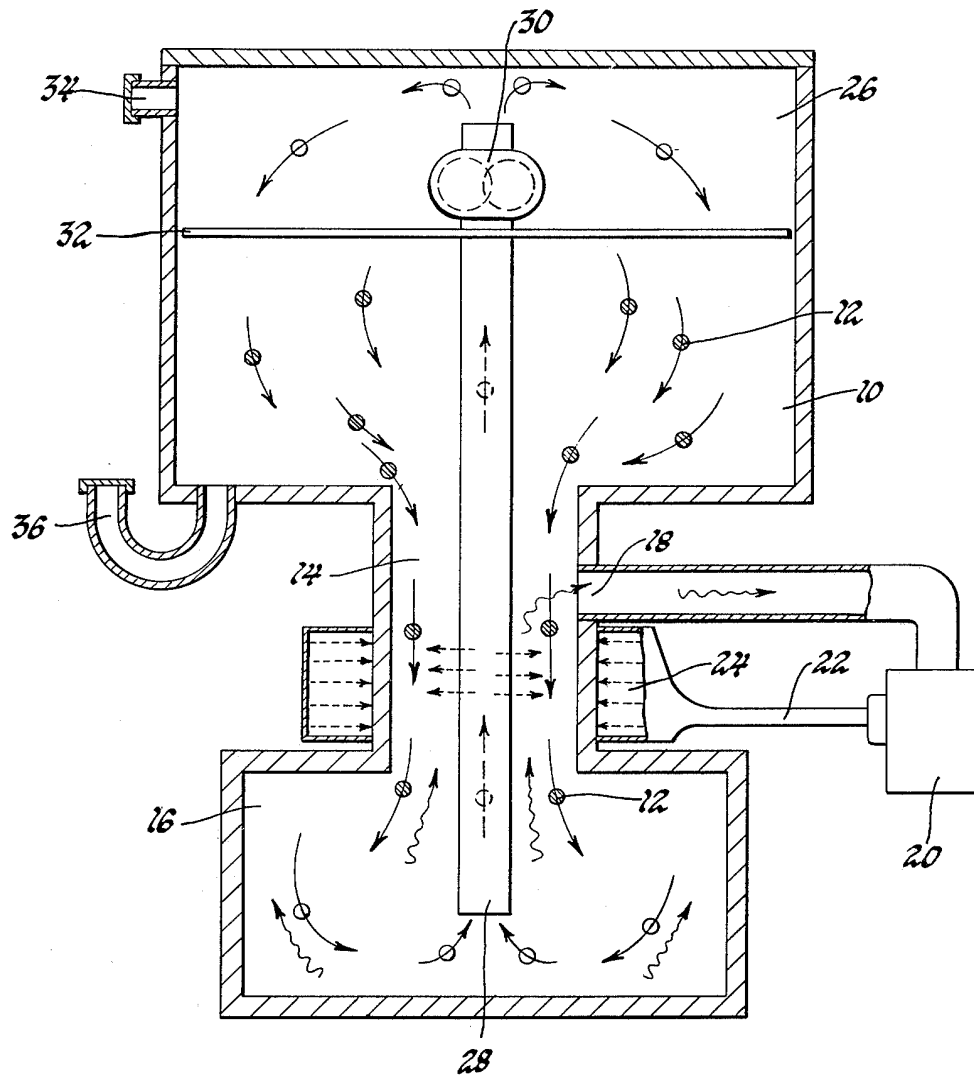
Hydrogen gas filled hollow hole-free microspheres are stored in a chamber. The microspheres are directed from the storage chamber to a heated chamber where the hydrogen gas is diffused through the outer surface of the microspheres and delivered to an engine for use as a fuel. After substantially all the hydrogen gas is removed, the microspheres are transported to another storage chamber from which they are completely removed for refilling with hydrogen gas while the first mentioned storage chamber is refilled with fueled microspheres.

**2 Claims, 1 Drawing Figure**

U.S. Patent

May 11, 1982

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## HYDROGEN FUEL STORAGE AND DELIVERY SYSTEM

This invention relates to fuel storage systems and more particularly to such systems for storing and delivering hydrogen gas to an engine.

It is well-known that hydrogen is a very efficient and clean-burning fuel. There are, however, some difficulties in storing hydrogen, prior to its use within the engine. Most generally, the hydrogen is stored either in liquid form or as a gas under pressure in a large vessel. The liquid storage systems require significant insulation so that the liquid state can be maintained while the gas storage systems require large and heavy vessels.

The present invention utilizes microspheres filled with hydrogen gas at high pressure. The microspheres can be stored in conventionally designed storage chambers since they do not require ambient pressurization or substantial low temperature control. The process for storing gases in hollow hole-free microspheres is discussed in U.S. Pat. Nos. 2,892,508 issued to Kohman et al. June 30, 1959 and 3,184,899 issued to Frazier May 25, 1965.

More recent developments in the art of gas filled microspheres indicate that hydrogen gas can be stored at pressures of 400 atm.

It is therefore an object of this invention to provide an improved fuel storage and delivery system wherein hollow microspheres filled with hydrogen gas are stored in a fuel storage chamber from which the microspheres are directed through a heated delivery chamber wherein hydrogen gas is freed by diffusion and delivered to the engine after which the substantially emptied microspheres are delivered to a second storage chamber.

It is another object of this invention to provide an improved hydrogen storage and delivery structure wherein hydrogen gas filled microspheres are moved progressively from a storage chamber to a heated delivery chamber and diffusion chamber wherein the hydrogen gas is removed. From the diffusion chamber, the substantially emptied microspheres are removed by mechanical means, such as a pump, to a storage chamber from which they can be removed for refilling.

These and other objects and advantages of the present invention will be more apparent from the following description and drawing which is a diagrammatic representation of a fuel storage and delivery structure.

The structure has a fuel storage chamber 10 which is filled with microspheres 12. The microspheres 12 are closely packed in the fuel storage chamber 10 such that approximately 70% of the volume is filled with microspheres while the remaining 30% represents the spaces between microspheres. Thus, the fuel storage chamber has a packing fraction of 0.7. The microspheres 12 are directed from the fuel storage chamber 10 into a heated fuel delivery chamber 14 from which they pass into a diffusion chamber 16. The heated fuel delivery chamber 14 has connected thereto a fuel delivery passage 18 which is connected to a conventional hydrogen gas burning engine 20. As is well known, engines provided work output and waste heat. The waste heat from engine 20 is directed through a passage 22 into a chamber 24 which partially surrounds the heated fuel in delivery chamber 14. The heat from chamber 24 passes through the walls of the heated fuel delivery chamber 14 to cause the ambient temperature therein to rise.

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As is well-known, the gas contained within the microspheres 12 will diffuse through the microspheres at a rate which increases with increasing temperature. By maintaining the fuel storage chamber 10 at substantially low ambient temperatures, such as 24° C., the amount of hydrogen gas escaping from the microspheres will be minimal. However, by maintaining the temperature of the heated fuel delivery chamber 14 in the diffusion chamber 16, the range of 300° to 350° C., the hydrogen diffusion from the microspheres 12 will be quite rapid.

The diffusion chamber 16 is in communication with a microsphere storage chamber 26 through a delivery chamber 28. Delivery passage 28 has incorporated therein a pump 30 which is effective to deliver substantially empty microspheres from the diffusion chamber 16 to the microsphere storage chamber 26. To conserve space and to provide the smallest overall package available in the system, the microsphere storage chamber 26 and the fuel storage chamber 10 share common boundaries and are separated by a floating seal 32. The floating seal 32 can be of the rolling seal variety or of the floating piston variety, the construction of either of which is well-known.

When substantially all of the microspheres have passed from the fuel storage chamber 10 through chambers 14 and 16 to the microsphere storage chamber 26, the empty microspheres can be removed through an opening 34 while the fuel storage chamber 10 can be refilled with charged microspheres through an opening 36.

By maintaining low ambient temperature conditions whenever the engine 20 is inoperable, the diffusion rate of the hydrogen gas from the microspheres 12 is minimal such that pressure generated within the system is also minimal. This is true even though the pressure within the fully charged microspheres may be as high as 400 atm. Thus, the structural integrity of the chambers 10, 14, 16 and 26 does not require the use of heavy gauge or thick metal walls. Therefore, the overall weight of the system is similar to conventional gasoline storage systems. While the system shown is a substantially continuous flow type system, various structures could be used wherein each of the chambers is separated from its predecessor and means are provided for mechanically moving the microspheres from one step in the fuel storage and delivery process to the next.

It should also be appreciated that if sufficient diffusion of hydrogen gas does not occur during engine shut down to permit restarting, external heat, such as from an electrical heater, can be provided to generate sufficient fuel for engine start. It should also be obvious to those skilled in the art that the microspheres stored in chamber 26 are not completely empty, hydrogen gas which might diffuse therein can be delivered by various means to either chamber 10, 14, or 16.

Obviously, many modifications and variations of the present invention are possible in light of the above teaching. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A hydrogen fuel storage structure for storing hollow microspheres filled with hydrogen gas and for freeing the hydrogen gas from the microspheres for delivery to an engine, said storage structure comprising; a fuel storage chamber for enclosing a plurality of mi-

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microspheres filled with hydrogen gas; heated fuel delivery chamber means for freeing the hydrogen gas from the microspheres by heating; means for delivering the microspheres to the heated fuel delivery chamber means; means for delivering the freed hydrogen gas to an engine; means for directing the waste heat from the engine to heat the heated fuel delivery chamber; a microsphere storage chamber for storing the microspheres after the hydrogen gas is freed therefrom; and pump means for moving the microspheres from the heated fuel delivery chamber to the microsphere storage chamber.

2. A hydrogen fuel storage structure for storing hollow microspheres filled with hydrogen gas and for freeing the hydrogen gas from the microspheres for delivery to an engine, said storage structure comprising:

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a fuel storage chamber for enclosing a plurality of microspheres filled with hydrogen gas; heated fuel delivery chamber means connected to said fuel storage chamber for freeing the hydrogen gas from the microspheres by heating; a diffusion chamber adjacent said heated fuel delivery chamber for storing the microspheres at an elevated temperature after passage through said heated fuel delivery chamber; means for delivering the freed hydrogen gas to an engine; means for directing the waste heat from the engine to heat the heated fuel delivery chamber; a microsphere storage chamber for storing the microspheres after the hydrogen gas is freed therefrom; and pump means for moving the microspheres from the diffusion chamber to the microsphere storage chamber.

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**United States Patent** [19][11] **4,340,580****Suzuki**[45] **Jul. 20, 1982**[54] **METHOD OF PRODUCING HYDROGEN**[76] Inventor: **Masahiro Suzuki**, 423, Yasaka,  
Kakegawa-shi, Shizuoka, Japan[21] Appl. No.: **254,580**[22] Filed: **Apr. 16, 1981****Related U.S. Application Data**[63] Continuation-in-part of Ser. No. 93,660, Nov. 13, 1979,  
Pat. No. 4,269,818.[30] **Foreign Application Priority Data**

Nov. 13, 1978 [JP] Japan ..... 53-139632

[51] Int. Cl.<sup>3</sup> ..... **C01B 1/07**[52] U.S. Cl. .... **423/657; 423/636**[58] Field of Search ..... 423/657, 658, 636;  
204/45 R, 47, 48, 49, 52 R, 56 N[56] **References Cited****U.S. PATENT DOCUMENTS**2,389,181 11/1945 Brown ..... 204/48  
2,728,720 12/1955 Delong ..... 204/32 R3,030,282 4/1962 Passal ..... 204/52 R  
3,347,757 10/1967 Lacroix et al. .... 204/47  
4,072,514 2/1978 Suzuki ..... 423/657 X  
4,264,362 4/1981 Sergev et al. .... 423/657 X**FOREIGN PATENT DOCUMENTS**

2508450 9/1975 Fed. Rep. of Germany ..... 423/657

*Primary Examiner*—Edward J. Meros*Attorney, Agent, or Firm*—Blanchard, Flynn, Thiel,  
Boutell & Tanis

[57]

**ABSTRACT**

Hydrogen is produced by placing a magnesium electrode and another electrode in an electrolyte solution, applying a direct or an alternating current voltage between said electrodes for activating said magnesium electrode until the surface of the magnesium electrode turns blackish in color; then discontinuing said voltage and then generating hydrogen by placing the activated magnesium electrode in sea water or an aqueous solution of a neutral salt.

**5 Claims, No Drawings**

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## METHOD OF PRODUCING HYDROGEN

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of Ser. No. 93 660, filed Nov. 13, 1979, now U.S. Pat. No. 4,269,818, the entire contents of which is incorporated herein by reference.

## BACKGROUND OF THE INVENTION

The present invention relates to a method of producing hydrogen and more particularly to a method of producing hydrogen of extremely high purity, in a high yield, by a simple process that can be readily employed for practical use, without causing any pollution of the atmosphere.

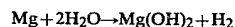
More particularly, this invention relates to a method of producing hydrogen, using a magnesium object having a highly activated surface. In this method, the magnesium object is chemically or electrolytically treated in an electrolytic solution to form an activated surface on the object by applying a direct current or an alternating current voltage. The thus-activated magnesium object is immersed in sea water or an aqueous solution of neutral salt to produce hydrogen.

In recent years, hydrogen has attracted attention as a potential fuel. On combustion, hydrogen does not produce substances which are apt to pollute the atmosphere such as, for example, sulfur oxides and nitrogen oxides. It is safe, unless it is handled carelessly, and it possesses outstanding properties as a fuel.

For the production of hydrogen, there have heretofore been developed methods involving operations on a large commercial scale such as, for example, the method of effecting electrolysis of water, the method of treating petroleum gas and coal gas, and the method utilizing the secondary production of hydrogen attendant upon the electrolysis of alkalis.

All these operations inevitably require the use of facilities of large dimensions and they are apt to produce air pollution substances.

As a further method of producing hydrogen, the reaction between magnesium and water is known. This reaction is illustrated by the following chemical equation:



In this reaction, once magnesium hydroxide is formed on the surface of the magnesium, the formed magnesium hydroxide prevents further contact of the magnesium with water, so that the reaction is stopped and therefore the generation of hydrogen is also stopped.

With respect to this reaction, as disclosed in British Pat. No. 579 246, it is known that if the magnesium, for use in the reaction according to the foregoing chemical equation, is prepared in the form of a mixture or alloy with a metal, such as iron, nickel or copper, the reaction velocity in the rightward direction of the equation is accelerated and the quantity of hydrogen generated is proportionately increased.

However, it is not always easy to prepare magnesium for use in the reaction in the form of a mixture or alloy with, for example, iron, nickel or copper.

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## SUMMARY OF THE INVENTION

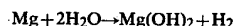
It is therefore a primary object of the present invention to provide a method of producing hydrogen by a simple process without causing any pollution of the atmosphere and in a high yield with a high purity.

Another object of the present invention is to produce hydrogen without requiring the use of facilities of large dimensions.

In the present invention, hydrogen is produced by immersing a magnesium electrode and another electrode in an electrolytic solution, applying a direct or an alternating current voltage across said electrodes until the surface of the magnesium electrode turns blackish in color in order to activate the magnesium and then immersing the magnesium electrode in a neutral salt solution or sea water.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Generally, the present invention is based on the decomposition of water in accordance with the reaction scheme set forth below:



This reaction, however, stops once magnesium hydroxide is formed on the surface of the magnesium, so that in practice, the amount of hydrogen generated by this reaction is extremely small. In the present invention, a magnesium electrode in any arbitrary physical form, such as a ribbon, a plate or particles, is immersed in an electrolytic solution also containing another electrode containing, for example, nickel, copper, carbon, iron or platinum. By applying a direct current or an alternating current voltage between those electrodes in the electrolytic solution, the surface of the magnesium is highly activated electrochemically and quickly turns blackish in color. When the thus-treated magnesium is then immersed in a neutral salt aqueous solution, such as aqueous solutions of NaCl, KCl, Na<sub>2</sub>SO<sub>4</sub>, K<sub>2</sub>SO<sub>4</sub>, NaNO<sub>3</sub> or KNO<sub>3</sub> or sea water, hydrogen is generated vigorously and continuously. A significant feature of this activation is that, once magnesium is activated in the above-mentioned manner, the magnesium is no longer deactivated.

This activation can be achieved by connecting the magnesium electrode and the other electrode across a direct current source supplying a voltage, for example, in the range of 5 V to 500 V, for a short period of time.

When the thus-activated magnesium is then immersed in the neutral salt aqueous solution or sea water, hydrogen is generated vigorously.

The present invention will be described more specifically by referring to preferred embodiments and comparative examples. The following examples should be interpreted as illustrative and not in a limiting sense.

## EXAMPLE 1

A magnesium piece 10 g in weight, connected as an anode, and a copper piece 20 g in weight, connected as a cathode, were placed in 1,000 ml of a 10 wt. % NaOH aqueous electrolyte solution and were connected to a direct current voltage supply of 500 V for 2 seconds which was effective to form a blackish and activated surface on the magnesium. When the activated magnesium was removed from the NaOH electrolyte solution and then was immersed in 1,000 ml of sea water, hydrogen was generated as follows:

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Immersion time (min.)	10	20	30	40	50	60	70	80
Cumulative volume of hydrogen (ml)	1,105	4,317	7,450	9,826	10,563	11,028	11,241	11,321

### EXAMPLE 2

A magnesium plate 5 g in weight and a copper piece 20 g in weight were placed in 1,000 ml of a 20 wt. % NaCl aqueous electrolyte solution and were connected to a direct current voltage supply of 100 V for 5 seconds, using the magnesium plate as an anode and the copper piece as a cathode. The surface of the magnesium plate was quickly changed to a blackish activated surface. When the activated magnesium plate was removed from the NaCl electrolyte solution and was immersed in 1,000 ml of another 20 wt. % NaCl aqueous electrolyte solution, hydrogen was generated as follows:

Immersion time (min.)	10	20	30	40	50	60
Cumulative volume of hydrogen (ml)	556	2,163	3,781	4,953	5,137	6,055

Similar result were obtained by applying an alternating current voltage in place of the direct current voltage.

### EXAMPLE 3

(comparison)

For comparison with the above-mentioned Examples, a magnesium plate of 1.1 g in weight was immersed in 1,000 ml of water. However, hydrogen was scarcely generated.

Similar results were obtained when the procedure was repeated by using a magnesium plate 1.0 g in weight in place of the magnesium plate 1.1 g in weight and using sea water in place of water.

Further, when 1,000 ml of a 20 wt. % KCl or Na<sub>2</sub>SO<sub>4</sub> aqueous solution was used instead of water, similar results were obtained.

From the foregoing results, it is manifest that the activated magnesium pieces obtained according to the present invention were quite effective, while comparative magnesium pieces which were not subjected to the activating treatment did not have an effect on the hydrogen-producing reaction.

### EXAMPLE 4

In a 1.5 l container containing 1,000 ml of sea water were placed a ribbon of magnesium measuring 1.2 g in weight, as an anode, and an iron piece measuring 10 g in weight, as a cathode. The magnesium plate and the iron piece were connected to a direct current supply voltage

of 12 V for 120 seconds. The surface of the magnesium plate was rapidly turned blackish and an activated surface was readily formed thereon. When the magnesium plate was taken from the sea water and was immersed in 1,000 ml of KCl aqueous solution containing about 60 g of KCl, hydrogen was generated as follows:

Immersion time (min.)	10	20	30	40	50	60	70	80
Cumulative volume of hydrogen (ml)	128	440	786	1,006	1,086	1,104	1,126	1,136

In Example 4, sea water, NaCl, Na<sub>2</sub>SO<sub>4</sub>, K<sub>2</sub>SO<sub>4</sub>, NaNO<sub>3</sub> and KNO<sub>3</sub> were employed instead of KCl, respectively. The results showed that almost the same amount of hydrogen as in Example 4 was respectively produced.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for producing hydrogen by the reaction between magnesium and water, which comprises the steps of:

immersing a magnesium electrode and a second electrode in an aqueous electrolyte solution, and applying a direct or an alternating current voltage between said electrodes for activating the magnesium electrode until the surface of the magnesium electrode turns blackish in color and is thereby activated so that the magnesium electrode will rapidly react with water over an extended period of time to generate a large volume of hydrogen; and then immersing the activated magnesium electrode in sea water or an aqueous neutral salt solution, without applying a voltage thereto, and thereby generating hydrogen.

2. A method as claimed in claim 1 in which said neutral salt is selected from the group consisting of NaCl, KCl, Na<sub>2</sub>SO<sub>4</sub>, K<sub>2</sub>SO<sub>4</sub>, NaNO<sub>3</sub> and KNO<sub>3</sub>.

3. A method as claimed in claim 1 or claim 2 in which said second electrode comprises nickel, platinum or iron.

4. A method as claimed in claim 1 or claim 2 in which said second electrode comprises copper or carbon.

5. A method as claimed in claim 1 or claim 2 in which said voltage is direct current voltage, said magnesium electrode is connected as the anode and said second electrode is connected as the cathode.

\* \* \* \* \*



**United States Patent** [19][11] **4,356,163****Davidson**[45] **Oct. 26, 1982**[54] **PROCESS FOR THE PRODUCTION OF HYDROGEN**[75] Inventor: **James G. Davidson**, Paducah, Ky.[73] Assignee: **Davidson Research Ltd.**, Grand Rapids, Mich.[21] Appl. No.: **334,879**[22] Filed: **Dec. 28, 1981**[51] Int. Cl.<sup>3</sup> ..... **C01B 1/02**[52] U.S. Cl. .... **423/657; 423/579; 423/648 R**[58] Field of Search ..... **423/657, 648 R, 579, 423/641**[56] **References Cited****U.S. PATENT DOCUMENTS**

883,531	3/1908	Foersterling et al.	
909,536	1/1909	Brindley .	
3,313,598	4/1967	Gluckstein .....	23/211
3,459,493	8/1969	Ross .....	23/1
3,490,871	1/1970	Miller et al. ....	23/210
3,729,548	4/1973	Lemke .....	423/371

4,010,249	3/1977	DuPont .....	423/657
4,162,302	7/1979	Hirayama et al. ....	423/648 R
4,230,682	10/1980	Bamberger .....	423/648 R
4,309,403	1/1982	Robinson et al. ....	423/648 R

**OTHER PUBLICATIONS**

Jacobson, *Encyclopedia of Chemical Reactions*, vol. VI, Reinhold Publishing Corporation (1956), pp. 256, 343.

*Primary Examiner*—Earl C. Thomas

*Assistant Examiner*—Wayne A. Langel

*Attorney, Agent, or Firm*—Waters, Lesniak & Willey

[57]

**ABSTRACT**

A process is provided for producing hydrogen by combining an alkali metal with H<sub>2</sub>O to produce hydrogen and an alkali metal hydroxide. The alkali metal hydroxide is then combined with an alkali metal to produce hydrogen and an alkali metal monoxide. The alkali metal monoxide is then processed through a series of reactions to reclaim the alkali metal for reuse in the hydrogen producing steps of the process.

**7 Claims, No Drawings**

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## PROCESS FOR THE PRODUCTION OF HYDROGEN

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to hydrogen, and, more particularly, to a process for producing hydrogen from H<sub>2</sub>O.

#### 2. Description of the Prior Art

The concern over the possible exhaustion of realistic sources of supply of fossil fuels has become widespread. This concern has led to increased research in developing alternative sources of energy. Of the various alternative sources of energy being explored, hydrogen appears to have significant potential as a universal fuel and energy source, with an abundant source of supply as a constituent of water.

Currently, the most prevalent means for commercially producing hydrogen from water has been electrolysis. However, current methods are costly, and none is competitive with fossil fuels. While a wide variety of thermal and chemical processes have been developed, none has provided an inexpensive and efficient means for producing hydrogen from water. A process that could economically and efficiently produce hydrogen from water would virtually eliminate the current energy crisis.

### SUMMARY OF THE INVENTION

According to the present invention, there is provided a unique process that economically and efficiently produces hydrogen from H<sub>2</sub>O. The process includes a unique sequential combination of chemical reactions. The first step of the process is to combine H<sub>2</sub>O and an alkali metal in a first reaction zone to produce hydrogen and alkali metal hydroxide. The preferred alkali metals are sodium and potassium, and mixtures thereof, with sodium being especially preferred. It is also preferred that the H<sub>2</sub>O be gradually added to the alkali metal in the reaction zone for the best reaction control. The hydrogen produced in the first reaction zone is removed and collected, and the alkali metal hydroxide formed is transferred to a second reaction zone where it is combined with an alkali metal to produce hydrogen and alkali metal monoxide, preferably at a temperature above 300° C.

The hydrogen is removed from the second reaction zone and collected, and the alkali metal monoxide is transferred to a third reaction zone where it is combined with oxygen to produce alkali metal peroxide, preferably at a temperature between about 300° to 400° C.

The alkali metal peroxide is then transferred to a fourth reaction zone where it is combined with carbon to produce alkali metal carbonate and alkali metal, preferably at a temperature between about 300° to 400° C.

The alkali metal is removed from the fourth reaction zone and is returned to either the first or second reaction zones for use in the first or the second stage reactions. The alkali metal carbonate is transferred to a fifth reaction zone and is heated to produce alkali metal, oxygen and carbon dioxide. The temperature should be in excess of 882° C., with in excess of about 973° C. being preferred. Further, reduced pressure on the order of about 50 mm. of Hg. is preferred. The alkali metal is then removed from the fifth reaction zone and returned

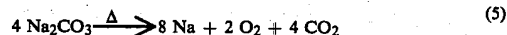
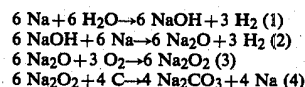
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to either the first or the second reaction zones for use in the first and second reactions.

A beneficial feature of the above sequence of reactions is that all of the reactions except the reaction in the fifth reaction zone are exothermic and release heat. Only the disassociation of the alkali metal carbonate in the fifth reaction zone to produce alkali metal, oxygen and carbon dioxide is an endothermic reaction which absorbs heat. Accordingly, in the preferred practice of the process of the present invention, the heat generated in the exothermic reactions is harnessed and utilized in the fifth reaction zone to minimize the external heat required for the requisite reaction in the fifth reaction zone. Also, it is preferred that the oxygen produced in the fifth reaction zone be collected and supplied to the third reaction zone as a reactant.

### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The unique process of the present invention comprises, in sequence, the following chemical reactions, wherein sodium is used by way of example as the alkali metal required in the process:



In the first reaction, H<sub>2</sub>O and an alkali metal are combined in a reaction zone to produce hydrogen and an alkali metal hydroxide, e.g., sodium hydroxide. Although any of the alkali metals, i.e., lithium, sodium, potassium, rubidium, cesium or mixtures thereof can be used as the alkali metal in the first reaction, potassium and sodium and mixtures thereof have been found to be preferred, with sodium being especially preferred. While H<sub>2</sub>O will combine with sodium to produce sodium hydroxide and hydrogen at any temperature greater than -80° C., the first reaction is generally run at ambient temperature, with the excess heat being generated by this exothermic reaction being utilized to add heat to the fifth reaction of the process which is endothermic.

The reaction zone is preferably a reaction vessel, such as a Monel lined steel or other non-corrosive covered reaction vessel with means for metered introduction of water and removal of hydrogen gas. The sodium, which is preferably in the solid state, is placed in the reaction vessel, and water is added to the sodium. Preferably, a vacuum is drawn before the water addition to minimize the amount of oxygen present to avoid ignition of the hydrogen or the sodium. The water should be added gradually so as to continually replace the water reacting the sodium. The procedure of gradual addition of the water to the sodium or other alkali metal avoids the explosive reaction between the alkali metal and the water which would otherwise take place.

Since the hydrogen generated from this first reaction will have some moisture content, it should be dried by conventional methods before storage or use.

The solid sodium hydroxide from the first reaction is then transferred to a second reaction zone, which can comprise a reaction vessel similar to the vessel utilized in the first reaction. In the second reaction, it is pre-

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ferred that the sodium be molten to optimize the mixing between the sodium hydroxide and the sodium for complete conversion of the sodium hydroxide to sodium monoxide and complete release of hydrogen gas. Accordingly, the reaction vessel should initially be heated to a temperature in excess of 300° C. to maintain the sodium in a molten state. However, since this reaction is also exothermic, excess heat will be generated to not only maintain the temperature in excess of 300° C. but will also yield excess heat which can be utilized in the fifth reaction which is endothermic. The hydrogen gas produced by the second reaction is generally dry and can be simply collected and stored.

The sodium monoxide is then transferred to a third reaction zone, which can be a similar reaction vessel with means for introducing gaseous oxygen. It is preferred that this reaction be run in excess of 300° C., with 300° C. to 400° C. being the preferred temperature range for this reaction. It is important that the oxygen be dry to prevent H<sub>2</sub>O from entering the reaction and converting the sodium monoxide to sodium hydroxide. Since this reaction is also exothermic, the heat generated will maintain the reaction vessel at the desired temperature, as well as providing excess heat to supplement the heat required in the fifth reaction which is endothermic.

The sodium peroxide produced in the third reaction vessel is then transferred to a fourth reaction vessel where it is combined with elemental carbon to produce sodium carbonate and sodium. Since it is preferred to run this fourth reaction at between about 300° C. and 400° C., an initial heat input is required to initiate the reaction at the desired rate. Care should be taken that the temperature does not exceed 460° C., which is the decomposition temperature of sodium peroxide. The sodium produced from this reaction is then returned to either the first or the second reaction zones for reuse, while the sodium carbonate is transferred to the fifth reaction zone.

Since the rate of the fifth reaction can be increased by lowering the pressure, a vacuum is applied to the fifth reaction vessel to reduce the pressure to approximately 50 mm of Hg. The temperature of the fifth reaction vessel should be in excess of about 882° C. and, preferably, in excess of about 973° C. Heat is applied to the reaction vessel until the sodium carbonate is completely disassociated into the gaseous constituents of sodium, oxygen and carbon dioxide. By cooling the reaction vessel to about 600° to 700° C., the oxygen and carbon dioxide can be removed as a gas while the sodium will condense to molten sodium, which can then be returned to either the first or second reaction zones.

Thus, by the unique sequence of reactions of the process of the present invention, virtually all of the hydrogen from the starting H<sub>2</sub>O is converted to gaseous hydrogen and collected and virtually all of the sodium is regenerated for reuse. In addition, the majority of the oxygen required in the third reaction zone can be supplied from the oxygen generated in the fifth reaction zone. Because the excess heat generated by the first four exothermic reactions can be utilized in the fifth endothermic reaction, the external heat required for the entire process is minimized. Accordingly, the process is efficient and economical and produces a valuable supply of hydrogen, with H<sub>2</sub>O being the only major consumed starting material.

In order to further illustrate the process of the present invention, reference is made to the following example:

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## EXAMPLE

11.0 grams of sodium are placed in a reaction vessel which is a commercially available Monel lined Parr 4541 high pressure reaction vessel, which can withstand pressures up to 2,000 p.s.i. A vacuum is drawn on the vessel to remove any oxygen which could result in the ignition of hydrogen or sodium in the vessel. 9 grams of H<sub>2</sub>O are added at a constant and gradual rate at the rate of approximately 2 ml./min. After all the sodium is reacted, an outlet valve is opened on the reaction vessel to release the hydrogen that is produced. The hydrogen is passed through a conventional mechanical or chemical dryer and is then ready for use or storage.

The sodium hydroxide is then transferred to a second reaction vessel which is also a Monel lined Parr 4541 reaction vessel. The weight of the sodium hydroxide is approximately 19.5 grams. In order to insure that the sodium hydroxide is dry, the sodium hydroxide is heated to approximately 300° C. to 320° C. and approximately  $\frac{1}{2}$  g. of molten sodium is added with agitation to react with any remaining H<sub>2</sub>O in the sodium hydroxide. 11.5 g. of molten sodium are then added at a constant rate of approximately 2 ml./min., with agitation. After all of the sodium has reacted, the reactor outlet valve is opened to release hydrogen, which is then passed through a conventional dryer to render it suitable for use or storage.

The sodium monoxide reaction product is then crushed into a very fine powder and transferred to a third Parr 4541 Monel lined reaction vessel. Approximately 31 g. of sodium monoxide are present in the third reaction vessel. The third reaction vessel is heated to approximately 350° C. and then pressurized with oxygen to about 500 p.s.i., followed by agitation so that the powdered sodium monoxide is uniformly exposed to the oxygen. The reaction is allowed to continue until approximately 8 g. of oxygen have been consumed in the reaction, which can be verified by the pressure drop in the reaction vessel. The excess oxygen is released to bring the reaction vessel to atmospheric pressure.

Approximately 39 g. of sodium peroxide which are produced in the third reaction vessel are transferred to a fourth Parr 4541 Monel lined reaction vessel. Approximately 4 g. of powdered charcoal (elemental carbon) are then added. Any available oxygen is removed to prevent the oxygen from reacting with the sodium. The temperature of the vessel is raised to approximately 400° C. and agitated until the reaction is complete.

The sodium carbonate produced in the fourth reaction vessel, which weighs approximately 43 g., is transferred to a fifth reaction vessel, which is a corrosion resistant, low pressure vessel. The vessel is evacuated to about 50 mm. of Hg. and then heated to about 900° C. The vessel is maintained at approximately 900° C. until the reaction is complete, i.e., the sodium carbonate has disassociated into gaseous sodium, oxygen and carbon dioxide. The vessel is then cooled to about 600° C.-700° C., which condenses the sodium. The oxygen and carbon dioxide are then drawn off as gases, and the molten sodium is returned to either the first or second reaction zones.

In the above Example, potassium and sodium-potassium mixtures can be substituted for the sodium with similar results.

While the preferred embodiments of the present invention have been described, it will be obvious to those skilled in the art that various changes and modifications

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can be made in the process of the present invention without departing from the spirit thereof. Accordingly, the scope of the present invention is deemed to be limited only by the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A process for the production of hydrogen comprising in sequence:  
combining  $H_2O$  and alkali metal in a first reaction zone to produce hydrogen and alkali metal hydroxide;  
removing and collecting hydrogen from said first reaction zone and transferring said alkali metal hydroxide to a second reaction zone and combining it with alkali metal to produce hydrogen and alkali metal monoxide;  
removing and collecting hydrogen from said second reaction zone and transferring said alkali metal monoxide to a third reaction zone and combining it with oxygen to produce alkali metal peroxide;  
transferring said alkali metal peroxide to a fourth reaction zone and combining it with carbon to produce alkali metal carbonate and alkali metal;  
removing alkali metal from said fourth reaction zone and returning it to said first or said second reaction zone and transferring said alkali metal carbonate to a fifth reaction zone and heating it to produce alkali metal, oxygen and carbon dioxide; and,

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removing said alkali metal from said fifth reaction zone and returning it to said first or said second reaction zone.

2. The process according to claim 1 wherein said alkali metal is selected from the group consisting of sodium, potassium and mixtures thereof.

3. The process according to claim 2 wherein said alkali metal is sodium.

4. The process according to claim 3 wherein said  $H_2O$  is water and is gradually added to said alkali metal in said first reaction zone; said alkali metal hydroxide is combined with said alkali metal at a temperature greater than about  $300^\circ C.$ ; said alkali metal monoxide is combined with said oxygen at a temperature of about  $300^\circ$  to  $400^\circ C.$ ; said alkali metal peroxide is combined with carbon at a temperature of about  $300^\circ$  to  $400^\circ C.$ ; and said alkali metal carbonate is heated to greater than about  $882^\circ C.$  at a pressure less than atmospheric pressure.

5. The process according to claim 4 wherein heat generated from said first, second, third and fourth reaction zones is transferred to said fifth reaction zone.

6. The process according to claim 5 wherein oxygen produced in said fifth reaction zone is collected and supplied as a reactant to said third reaction zone.

7. The process according to claim 6 wherein the reaction in said first reaction zone is run at less than atmospheric pressure to remove available free oxygen from the reaction zone.

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# United States Patent [19]

O'Hare

[11] **4,362,137**  
[45] **Dec. 7, 1982**

## [54] HYDROGEN PYROLYSIS FUEL INJECTION

[76] Inventor: **Louis R. O'Hare**, 1041 Ponderosa #2, Ft. Collins, Colo. 80521

[21] Appl. No.: **147,486**

[22] Filed: **May 7, 1980**

[51] Int. Cl.<sup>3</sup> ..... **F02B 43/08; F02M 31/20; F02M 31/02**

[52] U.S. Cl. .... **123/295; 123/541; 123/3; 123/DIG. 12; 123/557; 239/13; 239/132.1; 239/133**

[58] Field of Search ..... **123/1 A, 3, 536, DIG. 12, 123/538, 295, 294, 557, 549, 540, 541; 239/132, 132.1, 133, 135**

## [56] References Cited

### U.S. PATENT DOCUMENTS

2,448,950	9/1948	Barber et al.	123/295
2,886,014	5/1959	Konrad et al.	239/132
3,868,939	4/1975	Friese et al.	123/557
3,892,211	7/1975	Oyama	123/540

### FOREIGN PATENT DOCUMENTS

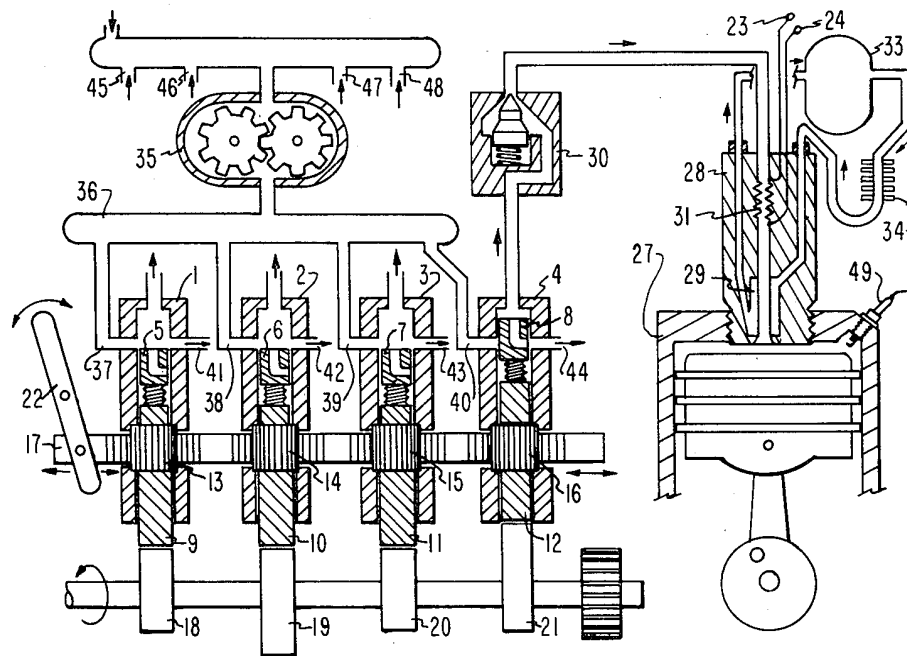
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Primary Examiner—Craig R. Feinberg

## [57] ABSTRACT

An ultralean fuel mixture ignition and induction system is disclosed in which very lean fuel-air mixtures are used in internal combustion engines by means of a novel method and apparatus which greatly increases the burning rate of extremely lean mixtures to thereby prevent afterfire and backfire which would otherwise result from these lean mixtures when used in an engine, this same improvement in burning rate being able to provide improved fuel economy in that less fuel is required per combustion event and it is also able to provide better control over exhaust emission products in that combustion is cooler and more complete. The increased burning rate producing these effects is achieved when fuel that is being directly injected by conventional methods is routed through a pyrolysis cell and a cooler on its way to the combustion chamber, the fuel being thereby stripped of some of its hydrogen and being thereby impelled along with the hydrogen into the cylinder during the compression cycle.

**4 Claims, 3 Drawing Figures**



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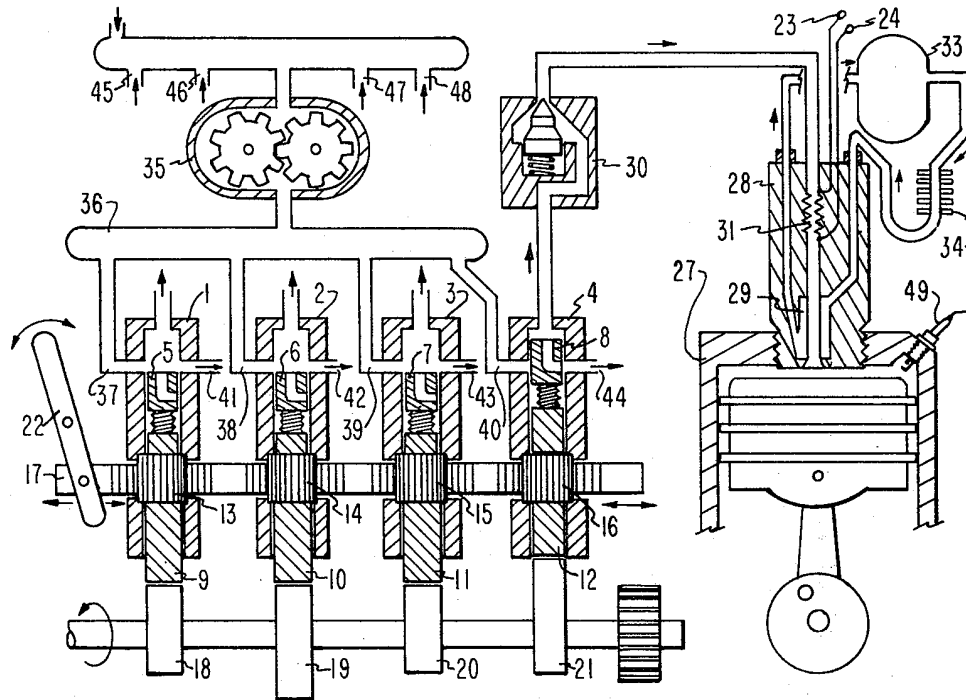


FIG. 1

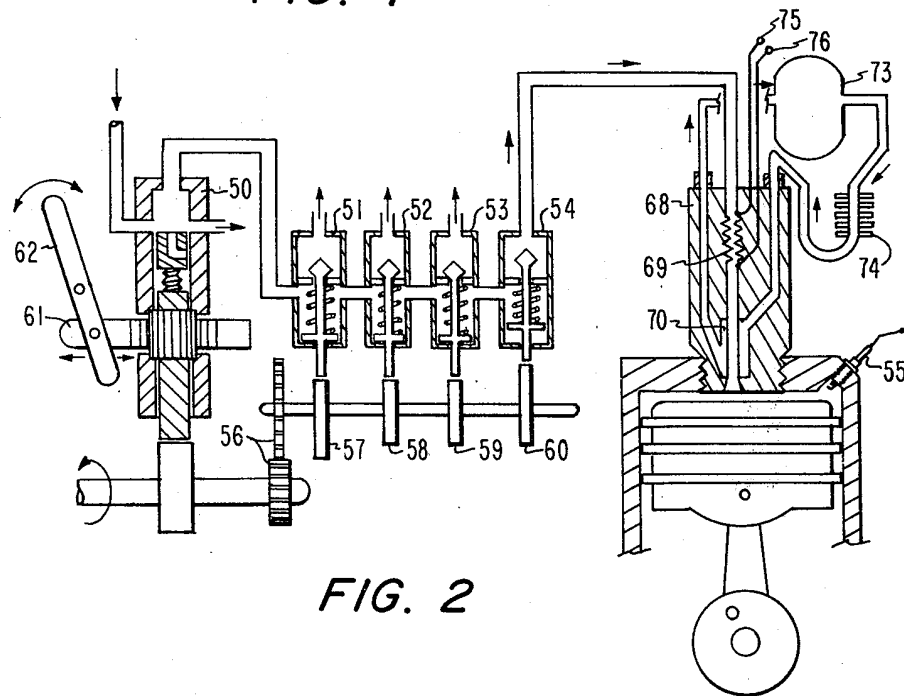
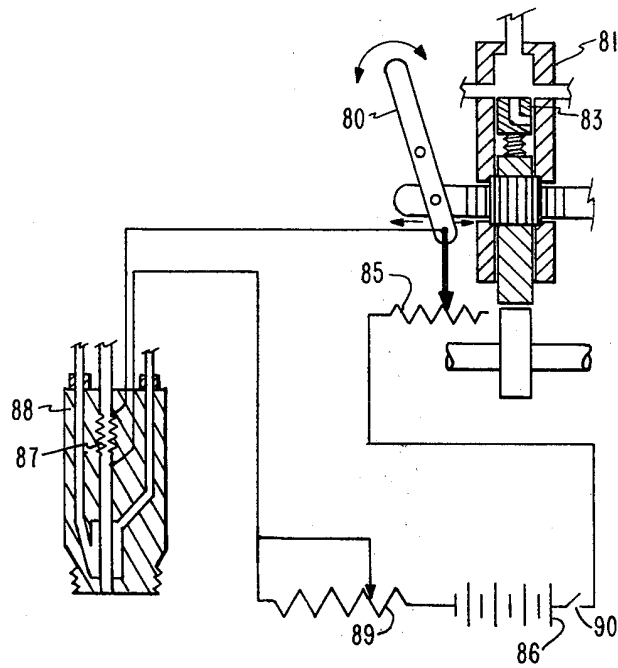


FIG. 2

U.S. Patent Dec. 7, 1982

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**FIG. 3**

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## HYDROGEN PYROLYSIS FUEL INJECTION

This present invention relates to internal combustion engine induction-ignition systems such as spark ignition systems and fuel injection ignition systems. Many elements of this system are similar to the diesel ignition system in which fuel under great pressure is injected into highly compressed and highly heated air and in which ignition of the fuel takes place when the fuel ignites upon contacting the compressed air. Like the diesel system this present system relies on hydraulic injection pressure on the fuel to force the fuel into the combustion chamber against the pressure of the compressed air in the combustion chamber, but it is unlike diesel fuel injection in that ignition does not take place when the fuel contacts the compressed air. In this invention the fuel air mixture is ignited later in the compression cycle by a separate means such as spark ignition. This present system, just as the prior systems mentioned, provides for the induction of fuel directly into the combustion chamber during the compression stroke by high fluid pressure exerted on liquid fuel to force it against compressed air in the combustion chamber; however, an aspect of the inventive concept of the present system is that, while injecting the fuel under the great hydraulic pressure on the liquid fuel, nevertheless pressure on the liquid fuel does not deliver only liquid fuel to the combustion chamber but hydrogen gas as well. Hydraulic pressure of the fuel injector pump forces liquid fuel into a pyrolysis cell or other dehydrogenator and then out of this cell into a cooler and finally into the combustion chamber. The liquid fuel is converted in route into a mixture of gas-vapor-liquid and this mixture remains under the influence of the hydraulic pressure placed on liquid fuel as it was pumped through the fuel injector pump. Since hydraulic pressure of fuel injector dimensions is made to act on the hydrogen formed downstream in the hydrolysis cell, hydrogen injected into the combustion chamber does not displace any air taken into the cylinder during the intake stroke. In conventional hydrogen enrichment systems hydrogen taken in along with air through the air intake necessarily displaces a volume of air decreasing volumetric efficiency. Turbocharging equipment and energy are required if compensation is to be made for the loss in volumetric efficiency. Accordingly, a point of difference between this present inventive concept and the prior art is the use of the liquid fuel injector to provide the injection of a quantity of gaseous hydrogen to be injected into the combustion chamber.

This present invention then does use other prior art in that it makes use of the art of hydrogen enrichment for the purpose of operating internal combustion engines on ultralean gas-air mixtures. This art is described in *NASA General Aviation Research Overview* 1976 by Roger L. Winblade and Judy A. Westfall at NASA Headquarters Washington, D.C. and published by The Society of Automotive Engineers in their publication number 760458 and the report number TMX 33-760 with the title, "New Potentials for Conventional Aircraft When Powered by Hydrogen Enriched Gasoline" by the authors Wesley A. Menard, Philip I. Moynihan and Jack H. Rupe of the Jet Propulsion Laboratory. The prior art described there uses hydrogen to increase the burning rate of very lean gas-air mixtures. Without the admixture of hydrogen gas the mixtures of fuel and air used in this art would be of such an order of leanness that their

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burning rates would be so slow as to produce afterfire and backfire in an internal combustion engine even though the total energy of the mixtures is adequate to operate the engine at normal power output. However, the induction system for inducting the hydrogen into the gas-air mixture acts against volumetric efficiency and reduces the overall efficiency of the engine because, for any given standard volume of hydrogen inducted into a cylinder, just that much air must be excluded since the volume of the cylinders is fixed. This difficulty is overcome in the prior art by the use of turbocharging wherein additional energy is extracted from the engine to operate the turbocharger to compress a greater quantity of air into the cylinder thereby compensating for the quantity and volume of air that is displaced by the hydrogen gas. In the present invention, however, the quantity and volume of air that is inducted into any cylinder is always the same as it would be without the addition of the hydrogen. This is because the hydrogen is not drawn into the cylinder along with the air to thereby occupy a certain percentage of the total volume of the filled chamber but rather the hydrogen is added only after the valves are closed and the compression stroke is taking place. It is only at that time that the action of the fuel injector pump impelling liquid fuel causes hydrogen gas to be formed and forced into the cylinder as it is only at that time that the liquid fuel is driven through the pyrolysis cell removing some hydrogen from the liquid injected fuel. While the use of hydrogen for a twenty percent reduction in gasoline consumption isn't unique to this present invention, nevertheless the method and means of formation and insertion is a novel simplification and improvement in the art.

A principal object of this invention then is to provide greater economy of operation for non-boosted gas engines by the use of the leanest possible mixtures consistent with normal power operation. Another object of the invention is to provide a very simple means of hydrogen production and induction still preserving volumetric efficiency. A further objective is to provide a means of internal cooling other than the use of fuel for internal cooling thereby maintaining internal cooling conditions necessarily required for low engine wear. Since either air or fuel may be used for internal cooling, it is preferable to use an excess of air where it is possible to control the burning rate of fuel. The invention's object then is to provide a cool but completely burning lean fuel mixture. In short the object is the practical use of hydrogen enrichment to increase to normal burning rates the otherwise slow burning rate of very lean fuel-air mixtures in gasoline engines. Finally since the combustion temperatures are low with this type of internal cooling, few nitrogen oxides are formed and control is made available over exhaust gas emissions.

Further clarification of the objectives and the way in which they are achieved may be seen from the following detailed description of the working mechanism and the method of operation. A conventional type of reciprocating gasoline engine is fitted with a direct fuel injection system. (The term "direct" here is used in distinction to indirect injection in which fuel is sprayed outside the intake valve.) The fuel injection system is the conventional direct fuel injection system of the type employed in the diesel engine art. The manner in which the injection system is operated is also to some degree conventional but with certain distinctive variations. It is used in a conventional manner to achieve fuel metering



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and fuel induction directly to the combustion chamber during the compression stroke. However, the period during which injection actually takes place is different and it is adjusted so that direct injection begins immediately after the intake valve closes on the compression stroke and ceases injecting in the period immediately before the period when conventional spark ignition takes place. Conventional electric spark plug ignition is employed and it is timed in a conventional way to prevent detonation and to have maximum pressure occur within a few degrees after the beginning of the power stroke. Again the injection system of this present invention is distinctive and different from that of the diesel in that the fuel of this system is not injected a few degrees before the top of the stroke nor does the ignition cause ignition by the mere contact between the fuel and the hot compressed air as it does in the case of the diesel. In this inventive concept the fuel with the hydrogen gas taken from it is injected at approximately fifty degrees into the compression stroke and after the closure of the intake valve in order that there will be approximately a hundred degrees of piston movement during which the hydrogen will diffuse throughout the air compressing in the cylinder before ignition takes place. The diffusing time is distinctive of this injection system because the admixture of air and hydrogen assures the rapid burn of the mixture later when it is ignited. Another distinguishing characteristic of this invention is the placement of a pyrolysis cell or pyrolizer between the fuel injector metering pump and the fuel injector nozzle. This cell is downstream of a fuel injector valve to assure that only highly pressurized fuel in the quantity metered by the metering pump can enter the cell and the cylinder. Following the pyrolysis cell and in the fuel stream before the cylinder is a cooler to lower the hot fuel from the pyrolizer to a temperature below ignition temperature.

Just as in conventional fuel injection systems more fuel must be metered and pumped to the cylinder for each combustion event and in the same way more air must be inducted as the power control rack is moved in the direction of higher power, so also in this invention conventional methods are used to increase fuel quantity per combustion event. An example of this is the lengthening of the stroke of the piston in the fuel metering injector pump and inducting more air through the air intake. But in this invention there is the added requirement of removing more hydrogen for more hydrogen injection as the fuel flow to the cylinder increases. This may be done in a number of ways in various embodiments. In one embodiment the control rack is used to vary the position of controls that regulate the amount of energy used to heat the pyrolysis cell so that, as the rack is moved in the direction of higher power output linkage from the rack moves a reostat control reducing the resistance of the reostat to send more current through an electric circuit to a resistance heater in the pyrolysis cell. The cell thereby removes more hydrogen from the fuel flowing through it. This linkage control in one embodiment takes the form of an electric power control which varies the resistance of a small variable resistor which in turn controls a solid state current regulator that admits more current to the electric heater in the pyrolysis cell as the rack is moved toward the high power position and visa versa.

The method I have invented for hydrogen enrichment then consists in fuel metering and pressurization for direct injection in such a way that discrete fuel

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quantities for each combustion event in each cylinder are metered and pressurized for delivery to each cylinder in the proper time sequence so that each discrete quantity metered for each cylinder is routed to its particular cylinder for arrival and injection during the compression stroke of that cylinder. The next step in this method consists in converting each discrete metered quantity of fuel by dehydrogenation especially by pyrolysis into a liquid-vapor-gas mixture while still under the pressure of the injector pump, then cooling this mixture in a cooler to a temperature below the temperature which would produce ignition in the combustion chamber, and then injecting the mixture into the proper cylinder at a period of the compression stroke sufficiently early in that cycle to permit hydrogen diffusion into the compressed air and then igniting the fuel air mixture by conventional electric spark ignition.

Clarification of the method and the means used in this ultralean mixture system is had by referring to the following drawings.

FIG. 1 of the drawings shows a diagram of direct fuel injection using an individual pump injection system with one of the injection pumps connected to one of an engine's cylinders that has received injected fuel during its compression stroke via a pyrolysis cell and a cooler. A single cylinder is shown for purposes of illustration and other cylinders that connect in the same fashion to the other injector pumps are not shown.

FIG. 2 of the drawings is a diagram of a fuel injection system using a high pressure distributor system and the pyrolysis cell of this invention. It shows one of the high pressure lines from one of the high pressure distributor valves connected to a pyrolysis cell followed by a cooler and the cylinder.

FIG. 3 shows a control rod link to a rack used to control pyrolysis cell output.

Referring then to FIG. 1 of the drawings, high pressure metering injector pumps, 1,2,3 and 4 have metering pistons 5,6,7 and 8. The stroke of these pistons is variable by means of a threaded sleeve which is able to either extend or shorten the effective length of the piston depending upon the direction of rotation of the piston's extension. The various extension sleeves 9,10,11 and 12 are in turn respectively rotated by pinions 13,14,15 and 16 which in turn are rotated by the back and forth movement of the rack 17. The rotation caused by the rack moving in one direction increases the length of the piston extensions causing them to make earlier contact with cams 18,19,20 and 21. The earlier contact causes the pistons to have a longer stroke and to thereby pump more fuel so that the fuel flow per injection stroke is determined by the relative position of the rack and by how far and in which direction the pinions have been rotated. Rack 17 thereby exersizes control over the engine's power output. Control rod 22, that controls the rack, also controls the energy that heats the pyrolysis cell to regulate the amount of hydrogen to be removed from the fuel flowing through the cell. The use of this control rod 22 to control pyrolysis heat and hydrogen quantity is shown in FIG. 3. In FIG. 1 the high pressure metering injector pumps 1, 2, 3 and 4 each deliver metered pulses of fuel to engine cylinders through pyrolysis cells and coolers. For the sake of simplicity in the drawings only one cylinder 27 with its pyrolysis cell 28 and cooler 29 is shown. Injector pump 4 meters discrete quantities of fuel through pressure valve 30 to resistance heater 31 of pyrolysis cell 28 where the fuel is heated to a pyrolysis temperature of

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between 650 degrees C. and 1000 degrees C. and usually about 850 degrees and some of the hydrogen is removed from the liquid fuel. The amount of hydrogen removed is generally not more than would produce an air-fuel mixture with a twenty five percent excess air. With hydrogen, less excess air than this generally causes detonation and backfire. The hydrogen-liquid fuel mixture from cell 28 is then cooled in cooling jacket 29 shown to be of a type through which liquid coolant circulates from pump 33 and cooling fins 34. This cooler may have another configuration in another embodiment of the invention. Instead of the cooling jacket around the injection duct as shown here, simple cooling fins, not shown, may be used around the duct to cool it as is practiced in the state of the cooling art. The pump 33 and the coolant it circulates is used to circulate coolant through the cooler following each cylinder's pyrolysis cell. The drawing does not show these simple connections for the sake of diagram simplicity. The low pressure pump 35 receives liquid fuel such as gasoline or alcohol from a fuel supply not shown. Pump outlet manifold 36 helps conduct fuel to injector pumps inlet ports 37,38,39 and 40. Fuel not used by the pumps is recirculated from injector pump excess fuel ports 41,42,43 and 44 back to low pressure pump's intake manifold through its ports 45,46,47 and 48. Spark plug 49 ignites the air-fuel mixture. Electric terminals 23 and 24 connect electric power to resistance heater of pyrolysis cell. Pressure operated valve 30 for purposes of illustration is shown at a distance from the pyrolysis cell but for most effective timing operation it should be in as close physical proximity to the cell as possible.

Referring then to FIG. 2 of the drawings, the high pressure metering injection pump 50 is the same as pump 4 of FIG. 1. The rapid output pulses of 50 are delivered in sequence to the cylinders one after the other by valves 51,52,53 and 54 in engine firing order. For diagram simplicity only valve 54 is shown connected but each valve has the same connections to its own cylinder. The pulse from each valve is timed to arrive at its cylinder in the compression cycle before conventional spark ignition from plug 55. Reduction gears 56 operate cams 57,58,59 and 60 to open valves 51,52,53 and 54 with each valve opening only once to exit one pulse for every four pulses of 50. These valves should be as close as possible to pyrolysis cell 68 and heater 69 which are the same as 28 and 31 of FIG. 1. Power rack 61 and control rod 62 are the same as rack 17 and control rod 22 of FIG. 1. In FIG. 2 pyrolysis cell 68 and heater 69 are the same as cell 28 and heater 31 of FIG. 1. Cooler 70 corresponds to 29 of FIG. 1. Pump 73 and fins 74 of FIG. 2 are the same as pump and fins 33 and 34 of FIG. 1. In FIG. 2 terminals 75 and 76 are the same as 23 and 24 of FIG. 1. In FIG. 2 spark plug 77 provides normal and conventional electric ignition.

Referring then to FIG. 3 and the use of the control rod link to control the hydrogen output of the pyrolysis cell, when the top of control rod 80 is moved to the right in this diagram and fuel pump 81, which is the same as pump 50 of FIG. 2, pumps more fuel with each stroke of its piston 83, then the slider of reostat 85 moves to the left and reduces its resistance. This causes more current to flow from battery 86 to electric resistance heater 87 of pyrolysis cell 88 thereby increasing the temperature of the cell and the quantity of the hydrogen removed from the fuel that is flowing through it. Variable resistor 89 is user to regulate the initial flow through the heater so that the heat and the rate of hy-

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drogen removal and hydrogen injection may be adjusted to the engine, to the type of liquid fuel being used and to the mixture ratio that is most useful for the particular conditions in which the engine is being operated. Switch 90 is closed during operation.

The individual pump system and the high pressure distributor system have been used to show how injector systems can be employed to operate a pyrolyzed fuel injection for gasoline type engines. In a similar manner other direct fuel injection systems are sources of injection energy for driving fuel through the pyrolysis cells and into the cylinders of an engine. Examples are electric direct fuel injection systems in which the metering injection pumps are driven electrically and timed electrically, as well as low pressure type distributor injection systems and unit injection systems and others that are known in the art.

The linkage that is used to move the control rod represented by 80 in FIG. 3 also operates the butterfly valve of the air intake system not shown. It causes both systems to operate in unison so that an increase in air intake results also in fuel intake increase. Adjustment is made on these linkage to set the fuel air mixtures according to standard practice in the fuel injection art. A lean mixture setting is effected when the linkage is coupled in such a way that the air butterfly valve is made to have greater opening than normal by its position on the link relative to the fuel metering control position on the link. In short both the air intake valve and the fuel metering increase-decrease adjustment rack move in unison so that an increase in airflow opening causes an increase in fuel intake and visa versa, but linkage is adjusted for lean mixtures by having the link keep the air intake valve open wider than normal as both move together. This system and other systems of fuel-air mixture control as practiced and known to those skilled in the fuel injection art are used to provide the lean mixtures which are the subject of this invention, but they are not shown in the drawings because they are conventional art.

This description of the invention is not meant to exclude other hydrogen enrichment using a pyrolysis cell with an injection system, and another embodiment of this basic inventive concept employs all the elements of the above description without the cooler after the pyrolysis cell, and it uses a different timing for the injected fuel. In this embodiment hydrogen is removed from injected fuel immediately before the fuel arrives in the combustion chamber. The fuel-hydrogen gas mixture is injected a few degrees before the top of the compression stroke, just before the power stroke begins. In this way the superheated fuel, along with the hydrogen stripped from it, ignites as it meets the hot compressed air near the end of the compression stroke. Ignition burning rate for very lean mixtures is accelerated as the hot hydrogen gas rapidly diffuses into the compressed air reacting with it as rapidly as it encounters unreacted oxygen.

The pyrolysis cell may be assisted by dehydrogenation catalysts placed in the heating chamber of the cell.

I claim:

1. A hydrogen enrichment fuel injection system for burning ultralean fuel-air mixtures in gasoline type engines comprising,

variable metering and high pressure pumping means for pumping discrete metered quantities of liquid fuel in consecutive pulses with these metered quantities being controllable to coincide with variable

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engine power demands, the greater the demand the more the fuel metered, and  
timing means whereby the consecutive pulses arrive at cylinders of the engine one after another, first at one cylinder then at another and so on in an order which is determined by engine firing order and at such a time duration in each cylinder that each cylinder receiving fuel in its proper sequence is at a period in its compression cycle when it begins to receive the pulse of fuel and has completed receiving the fuel pulse in a period before the completion of that same compression cycle and,  
pressure valving control means whereby fuel injection begins only when injection pressure is high enough to assure a positive pressure surge into the cylinder against air being compressed in each cylinder and,  
controlled hydrogen removal injector means comprising an injector housing containing a pyrolysis means comprising a chamber wherein each discrete fuel quantity is heated separately and by this heating effecting a partial pyrolysis of the liquid fuel thereby separating a quantity of hydrogen gas from the fuel and a cooling means for cooling a resulting

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mixture of the hydrogen gas and remaining fuel below ignition temperature by ducting said mixture through a cooler, wherein said mixture is injected into each cylinder while still under the pressure exerted by the fuel pumping means and,  
a fuel-air ignition means.

2. A hydrogen enrichment system as in claim 1 in which the duration of injection of the timing means injecting during the compression cycle begins after intake valve closure and is completed before a normal period of spark ignition in a gasoline type engine and in which the fuel-air ignition means is conventional spark plug ignition.

3. A hydrogen enrichment fuel injection system as in claim 1 in which the pressure valving control means is a pressure operated valve which provides positive opening operation when the injection pressure is above air pressure in each cylinder.

4. A hydrogen enrichment fuel injection system as in claim 1 in which the pressure valving control means is a series of cam operated high pressure valves with one of the series of valves in the injection line immediately before each injector housing.

\* \* \* \* \*

**United States Patent** [19][11] **4,376,097****Emelock**[45] **Mar. 8, 1983**[54] **HYDROGEN GENERATOR FOR MOTOR VEHICLE**[76] **Inventor:** Melvin Emelock, 1748 NW. 72nd Ave., Plantation, Fla. 33313[21] **Appl. No.:** 238,934[22] **Filed:** Feb. 27, 1981[51] **Int. Cl.<sup>3</sup>** ..... B01J 19/24[52] **U.S. Cl.** ..... 422/189; 48/61; 123/3; 123/DIG. 12; 180/65 R; 180/65 B; 422/193; 422/195; 422/199; 423/650; 429/17; 562/597[58] **Field of Search** ..... 422/188, 189, 191, 193, 422/195, 198, 199; 320/61; 48/61, 197 R, 197 A; 423/648 R, 650; 323/371; 429/17; 123/1 A, 1 R, 3, DIG. 12; 290/32, 50, 16, 17; 337/239, 276; 562/597; 180/65 R, 65 B, 65 C

[56]

**References Cited****U.S. PATENT DOCUMENTS**

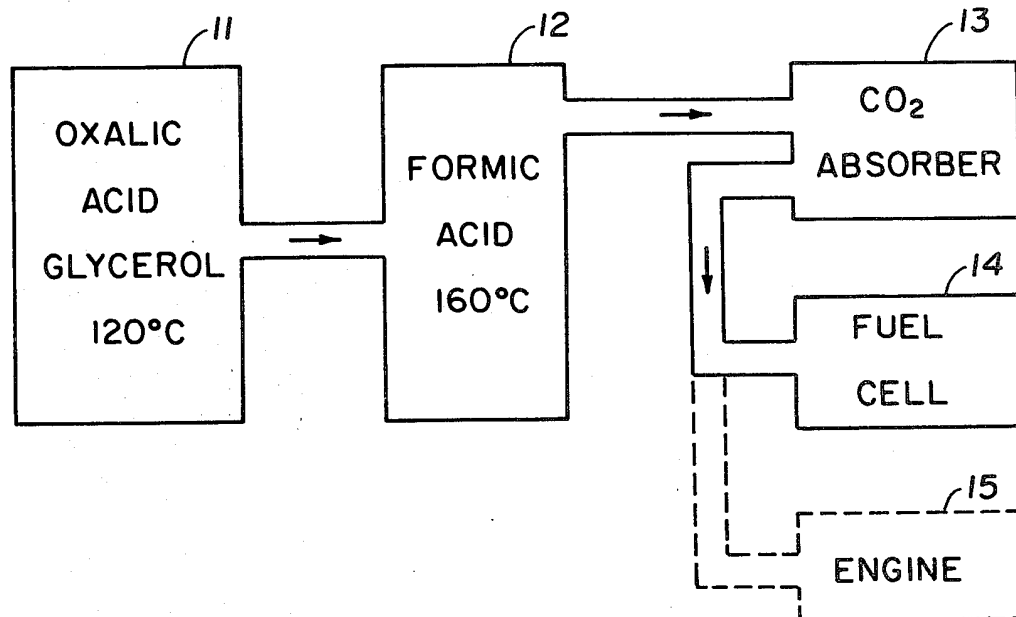
583,104	5/1897	Wattles	123/1 R X
1,363,488	12/1920	Uhlinger	423/650
1,790,635	1/1931	Arendt	290/17
1,970,634	8/1934	Steinmayer	337/239
3,107,304	10/1963	Fagel	290/17
3,313,598	4/1967	Gluckstein	423/648
3,517,766	6/1970	West	290/16 X
3,719,749	3/1973	Smith et al.	423/650
4,018,190	4/1977	Henault	123/DIG. 12
4,119,862	10/1978	Gocho	180/65 B X

*Primary Examiner*—Richard L. Chiesa*Attorney, Agent, or Firm*—Joseph Zallen

[57]

**ABSTRACT**

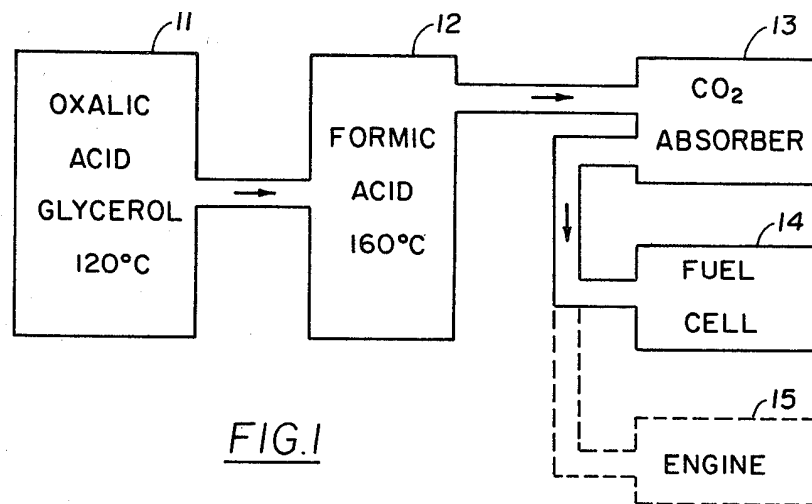
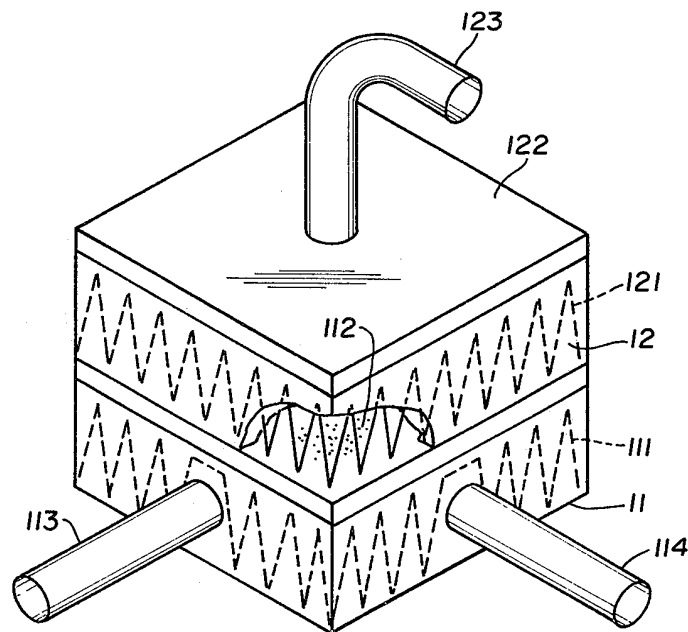
Oxalic acid, dispersed in glycerol is heated to form formic acid which is then heated at a higher temperature to form hydrogen. By-product carbon dioxide is absorbed. The hydrogen is used directly with a fuel cell to produce electricity or as fuel for an internal combustion engine.

**12 Claims, 2 Drawing Figures**

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FIG. 1FIG. 2

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## HYDROGEN GENERATOR FOR MOTOR VEHICLE

### BACKGROUND OF INVENTION

This invention relates to hydrogen generators. In particular it relates to hydrogen generators which are such size and weight as to be suitable for use in motor vehicles and the like.

As early as 1897 it was proposed to generate hydrogen as a fuel for an engine by reacting zinc or iron with sulphuric acid (U.S. Pat. No. 583,104). It has also been hitherto proposed to have an electric motor vehicle wherein an internal combustion engine drives a generator which in turn maintains the charge on the batteries for the electric motor vehicle (U.S. Pat. Nos. 1,970,634, 1,790,635, 3,517,766 and 4,119,862.) An electric vehicle has also been described in which an internal combustion drives an electric generator which in turn directly drives electric motors (U.S. Pat. No. 3,107,304). It has also been proposed to provide an internal combustion engine incorporated with a hydrogen generator wherein alcohol such as methanol is decomposed at a temperature of 200° to 400° C. in the presence of a catalyst such as zinc oxide-copper oxide. For a variety of reasons none of the prior art hydrogen generators are commercially feasible for motor vehicles.

One object of the present invention is to provide a novel hydrogen generator which is feasible for use in a motor vehicle.

Other objects and advantages of this invention will be apparent from the description and claims which follow taken together with the appended drawings.

### SUMMARY OF INVENTION

The hydrogen generator of the present invention utilizes a solid fuel, namely oxalic acid. The oxalic acid preferably in a liquid medium such as glycerol, is heated to form formic acid gas which in turn is heated to form hydrogen.

The reaction of heating oxalic acid forms carbon dioxide as a by-product and the heating of the formic acid gas also forms carbon dioxide as a by-product. Accordingly, one feature of this invention is to separate the carbon dioxide gas from the hydrogen gas as for example, by absorption in an alkaline solution such as calcium hydroxide.

The invention comprises broadly heating a mixture of oxalic acid and glycerol at a temperature of approximately 120° C., whereby formic acid and carbon dioxide are formed, heating the formic acid to a temperature of approximately 160° C. whereby hydrogen gas and carbon dioxide are formed, and conducting the hydrogen to either an internal combustion engine or a fuel cell. Where the hydrogen is conducted to an internal combustion engine it is preferred that the engine be stationary and constantly running so as to operate an electrical generator to maintain the charge in the battery. Where the hydrogen is conducted to a fuel cell it is contemplated that the current produced is fed directly to storage batteries, there preferably being a plurality of fuel cells to obtain the required voltage.

In one embodiment of this invention replaceable cartridges of oxalic acid are placed in a chamber where recirculating glycerol conducts the mixture to the first reaction chamber where the temperature is about 120° C. The formic acid formed in the first reaction chamber is then conducted to the second reaction chamber

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where at a temperature of 160° C. the hydrogen is formed. The first reaction chamber preferably has a heat-resistant gas permeable membrane so that the gases can escape without affecting the recirculation of the glycerol solution. The carbon dioxide is preferably separated from the hydrogen by absorption as for example, in a chamber of calcium hydroxide solution to form a precipitate of calcium carbonate.

The fuel cell that is preferred for use with this invention is one where the hydrogen does not have to be pure and where air could be used instead of pure oxygen. Carbon electrodes can be used because of the durability and a platinum type catalyst can be used to catalyze the reaction.

Heating of the reaction chambers can be done by the use of thermostatically-controlled electrical heating units within the walls of the reaction chambers. Alternately where an internal combustion engine is used the heat from the exhaust of the engine can be used to accomplish the chemical reactions. A vacuum pump is preferred to insure the removal of the gases from the second reaction chamber.

A preferred use of the invention is in connection with an electric vehicle powered by storage batteries. The oxalic acid fuel provides the energy for additional recharging of the batteries and thus can be operated on a steady basis on a vehicle.

The construction of the device is illustrated schematically. It is well within the scope of the chemical engineering art of today to select the appropriate materials, sizes and shapes of the materials of construction, sizes, arrangement and shapes of the various chambers and other components of the invention.

### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram of the invention.

FIG. 2 is a schematic diagram of a hydrogen generator made in accordance with this invention.

### SPECIFIC EXAMPLES OF INVENTION

Referring to the drawings, the oxalic acid dispersed in glycerol heated to 120° C. yields formic acid and carbon dioxide. The formic acid which is gaseous in form when now heated to 160° C. forms hydrogen gas and carbon dioxide. The carbon dioxide from both stages is absorbed and the hydrogen gas fed to either a fuel cell or an engine.

Oxalic acid dispersed in glycerol is placed in enclosed chamber 11 which has all solid walls except for the top wall 112 which is a gas-permeable, inert, heat-resistant membrane, as for example, fiberglass or ceramic. The walls of chamber 11 contain thermostatically controlled electric heaters which maintain the temperature of chamber 11 at approximately 120° C. Conduits 113 and 114 permit a continuous flow of oxalic acid and glycerol into chamber 11 from a source not illustrated.

As the oxalic acid decomposes into formic acid gas, the gas passes through membrane wall 112 to the second chamber 12 where thermostatically controlled electric heaters in its walls maintain the temperature of chamber 12 at approximately 160° C. The formic acid decomposes to form hydrogen gas. The hydrogen is passed through carbon dioxide absorber 13 and then fed to either a fuel cell 14 or as fuel to internal combustion engine 15.

The gases exit chamber 12 through exit conduit 123, to which a vacuum may be applied. The carbon dioxide

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absorber 13 may contain a slurry of calcium hydroxide. Although not illustrated it is contemplated that the recirculating glycerol, will be bringing in fresh oxalic acid in chamber 11 to replace the oxalic acid consumed, so that this is a controllable reaction. The hydrogen produced can be fed to fuel cells of various construction, but preferably those that do not require high purity as for example, a fuel cell utilizing aqueous sulphuric acid with carbon electrodes and a platinum-type catalyst.

I claim:

1. A hydrogen generating apparatus comprising a first chamber means containing a dispersion of oxalic acid in a liquid medium, first heating means associated with said first chamber means for heating said dispersion to a temperature whereby the oxalic acid decomposes to form formic acid gas and carbon dioxide, conducting means to transport said formic acid gas from said first chamber means to a second chamber means, and a second heating means, associated with said second chamber means for heating said formic acid so as to form hydrogen gas and carbon dioxide.

2. The apparatus of claim 1 wherein the medium is glycerol.

3. The apparatus of claim 1 wherein said first heating means causes said first chamber means to be maintained at a temperature of about 120° C.

4. The apparatus of claim 1 wherein said second heating means causes said second chamber means to be maintained at a temperature of about 160° C.

5. The apparatus of claim 1 which includes a fuel cell to which the hydrogen gas is conducted.

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6. The apparatus of claim 1 which includes an internal combustion engine to which the hydrogen gas is conducted.

7. The apparatus of claim 1 which includes means for absorbing the carbon dioxide formed during the reactions.

8. The apparatus of claim 1 which includes means for recirculating the dispersion through said first chamber means.

9. The apparatus of claim 1 which includes vacuum means for conducting the hydrogen gas out of said apparatus.

10. The apparatus of claim 1 which includes storage battery means, and fuel cells to which the hydrogen is conducted, the number of fuel cells being such as to supply the appropriate required voltage for the storage battery means.

11. The apparatus of claim 1 wherein said first chamber means includes an inert gas-permeable wall through which the formic acid gas can escape.

12. A hydrogen generating apparatus comprising a first chamber means containing oxalic acid, first heating means associated with said first chamber means for heating said oxalic acid to a temperature whereby the oxalic acid decomposes to form formic acid gas and carbon dioxide, conducting means to transport said formic acid gas from said first chamber means to a second chamber means, and a second heating means associated with said second chamber means for heating said formic acid so as to form hydrogen gas and carbon dioxide.

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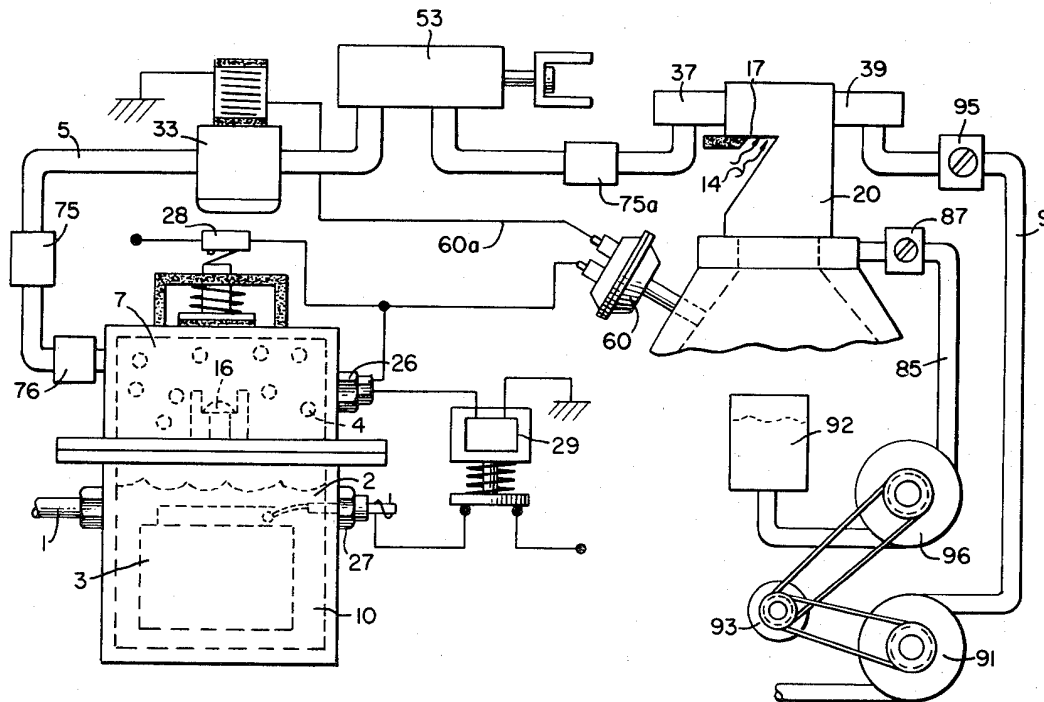
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**United States Patent** [19]**Meyer**[11] **4,389,981**[45] **Jun. 28, 1983****[54] HYDROGEN GAS INJECTOR SYSTEM FOR INTERNAL COMBUSTION ENGINE****[76] Inventor:** Stanley A. Meyer, 3792 Broadway Blvd., Grove City, Ohio 43123**[21] Appl. No.:** 349,185**[22] Filed:** Feb. 17, 1982**[51] Int. Cl.<sup>3</sup>** ..... F02M 23/04**[52] U.S. Cl.** ..... 123/3; 123/73 AD; 123/568; 123/DIG. 12**[58] Field of Search** ..... 123/1 A, 3, DIG. 12, 123/73 AD, 198 D, 568; 48/116, 180 CF**[56] References Cited****U.S. PATENT DOCUMENTS**1,996,861 4/1935 Dore et al. .... 123/198 D  
2,109,963 3/1938 Kruse ..... 48/180 C3,982,878 9/1976 Yamane et al. .... 123/1 A  
4,031,865 6/1977 Dufour ..... 123/DIG. 12  
4,059,086 11/1977 Tsubouchi ..... 123/73 AD*Primary Examiner*—William A. Cuchlinski, Jr.  
*Attorney, Agent, or Firm*—Anthony D. Cennamo**[57]****ABSTRACT**

System and apparatus for the controlled intermixing of a volatile hydrogen gas with oxygen and other non-combustible gasses in a combustion system. In a preferred arrangement the source of volatile gas is a hydrogen source, and the non-combustible gasses are the exhaust gasses of the combustion system in a closed loop arrangement. Specific structure for the controlled mixing of the gasses, the fuel flow control, and safety are disclosed.

**19 Claims, 9 Drawing Figures**

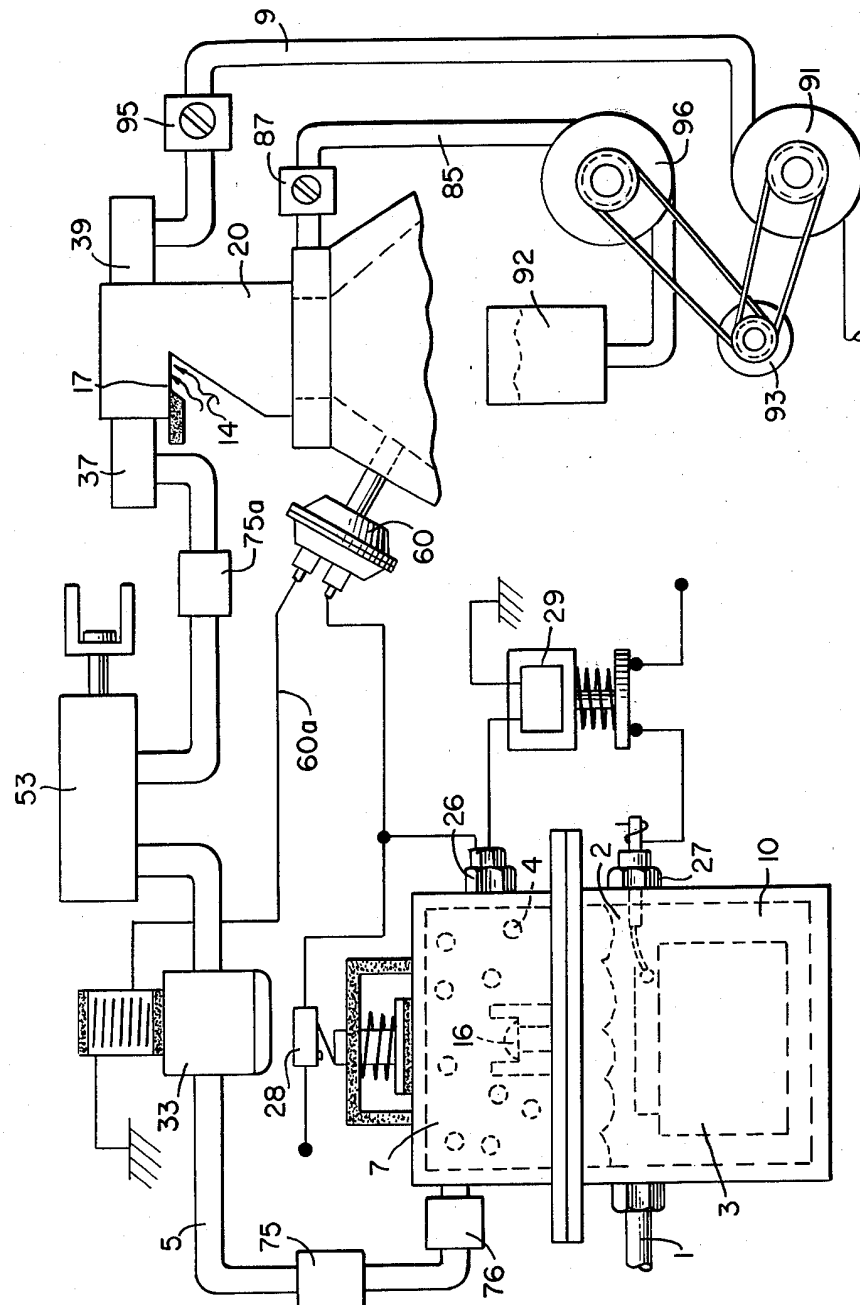


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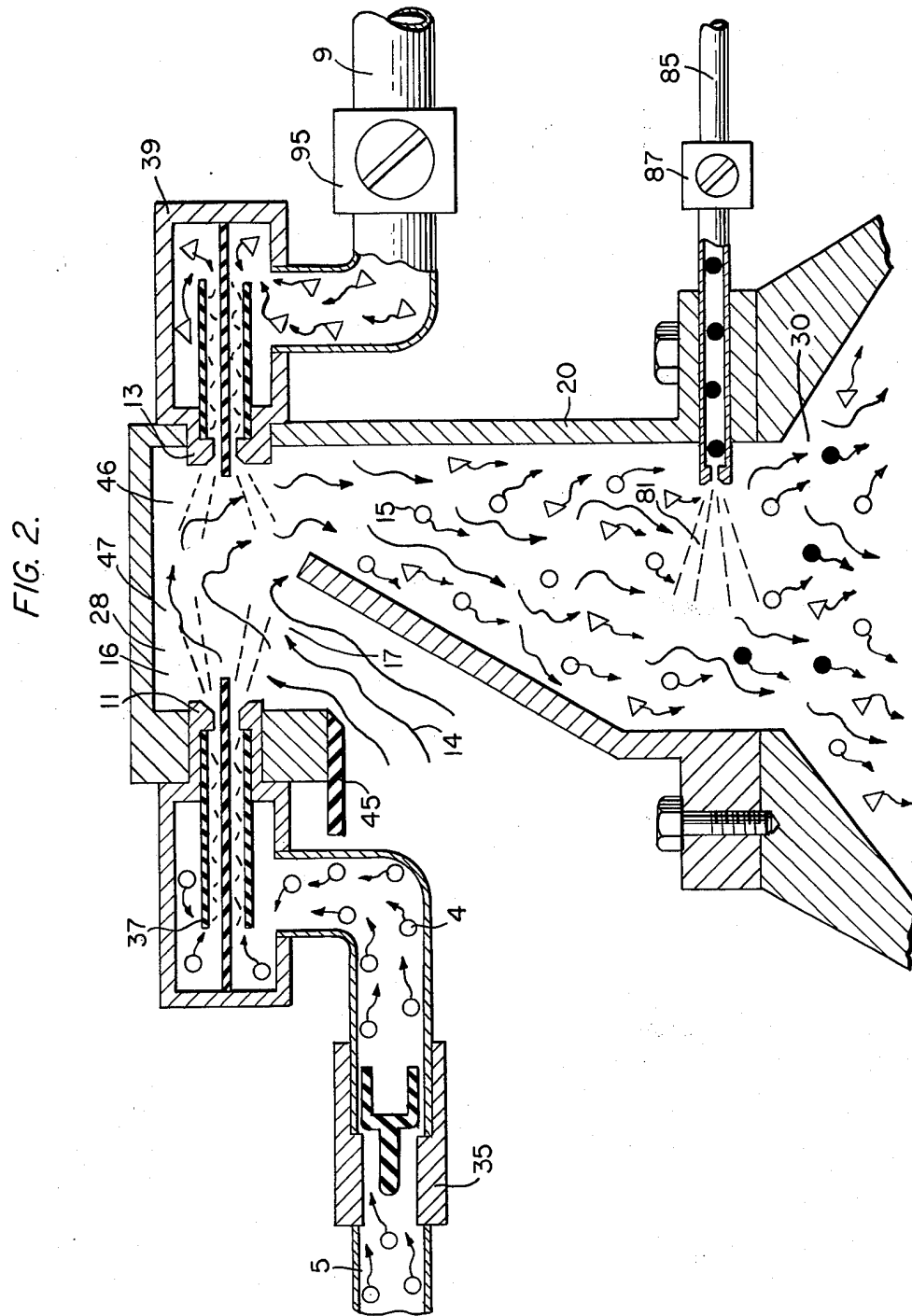
FIG. 1.



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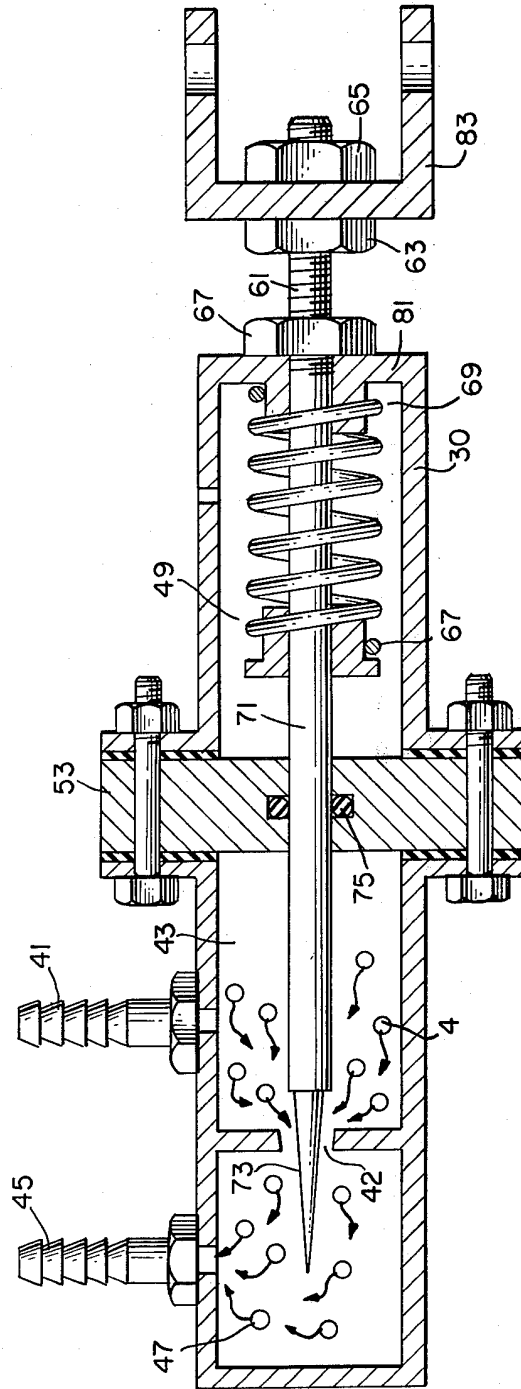


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FIG. 3.

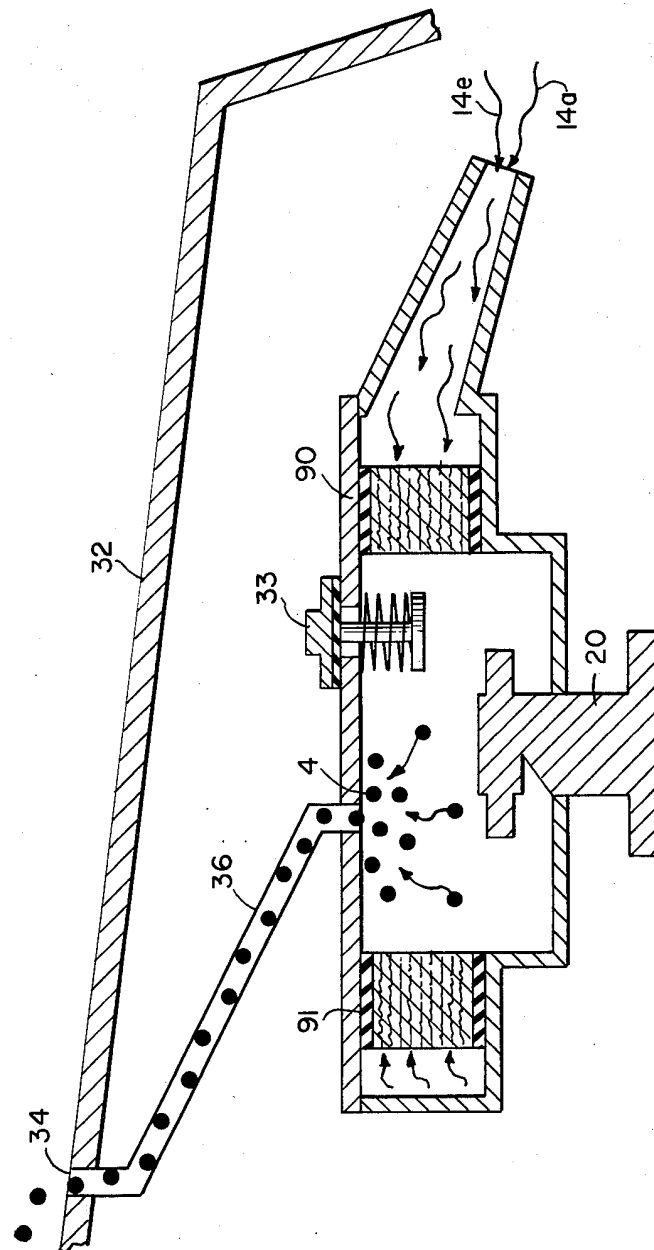


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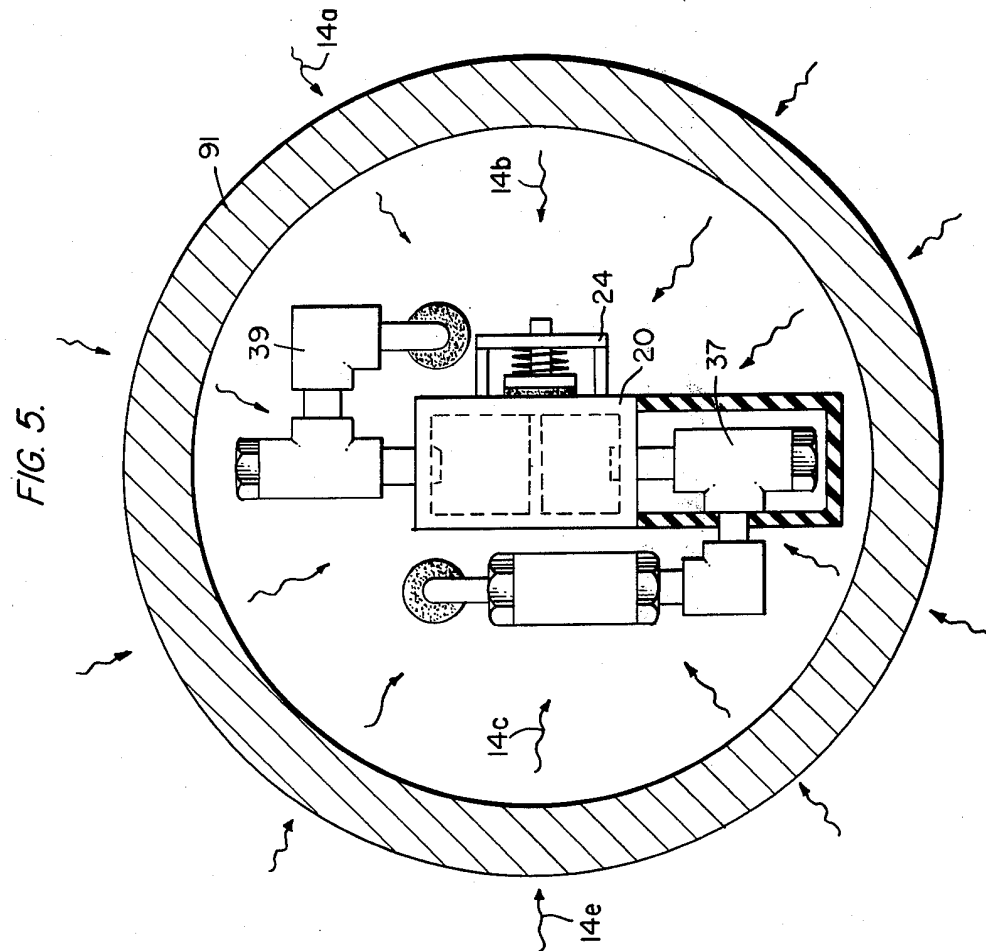
FIG. 4.



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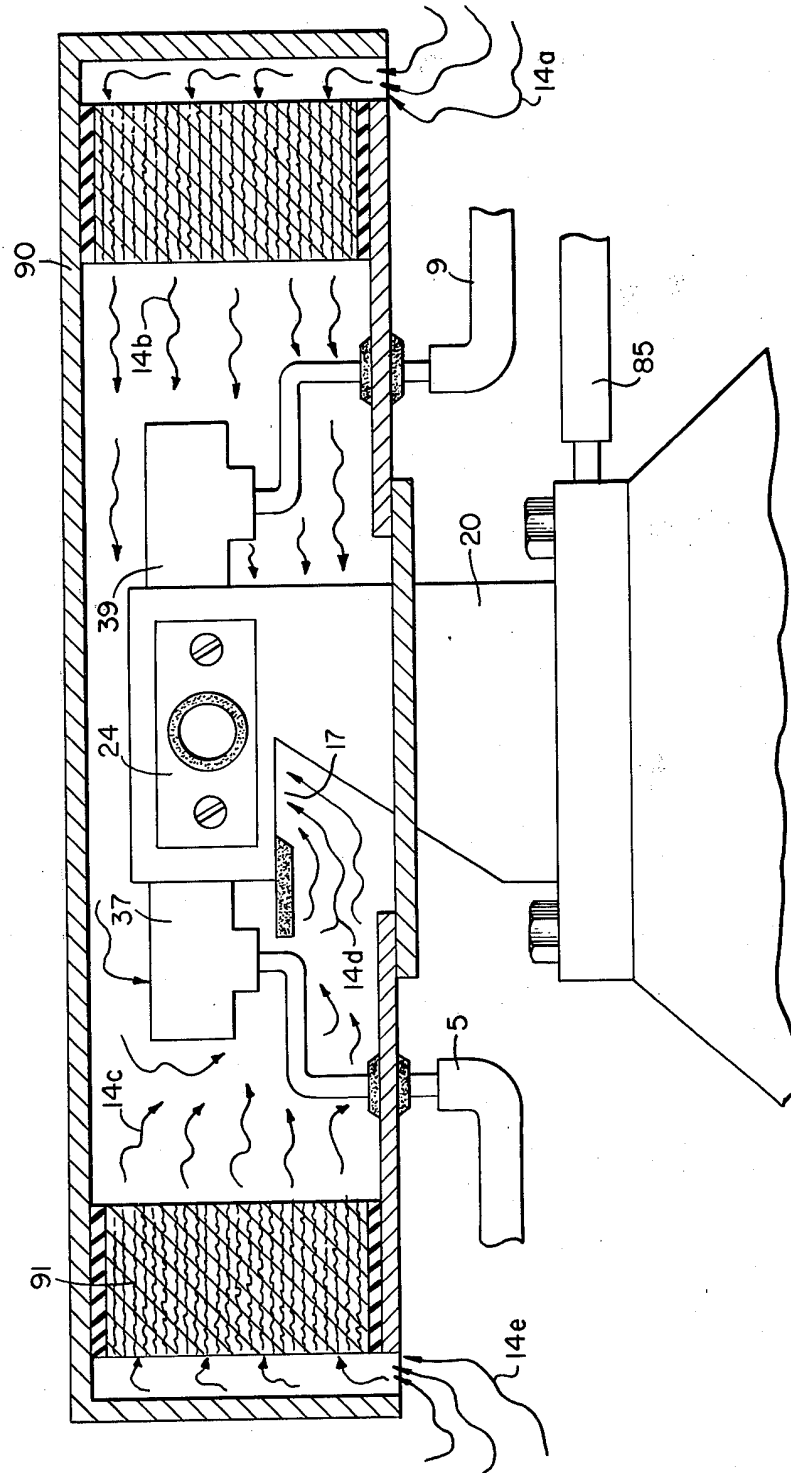


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FIG. 6.



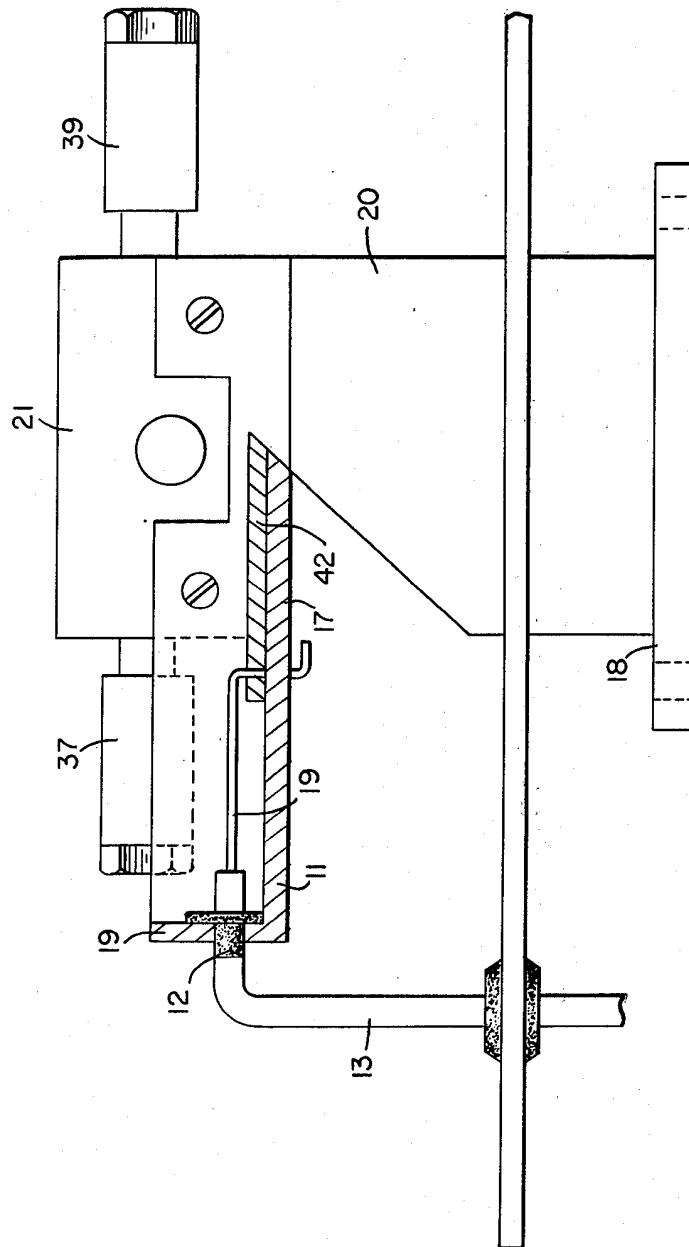
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FIG. 7.

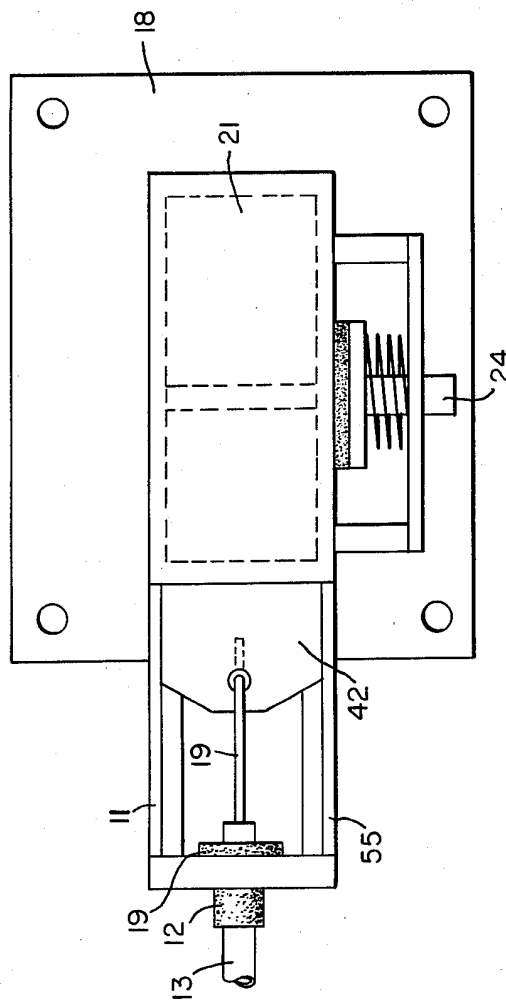


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FIG. 8.



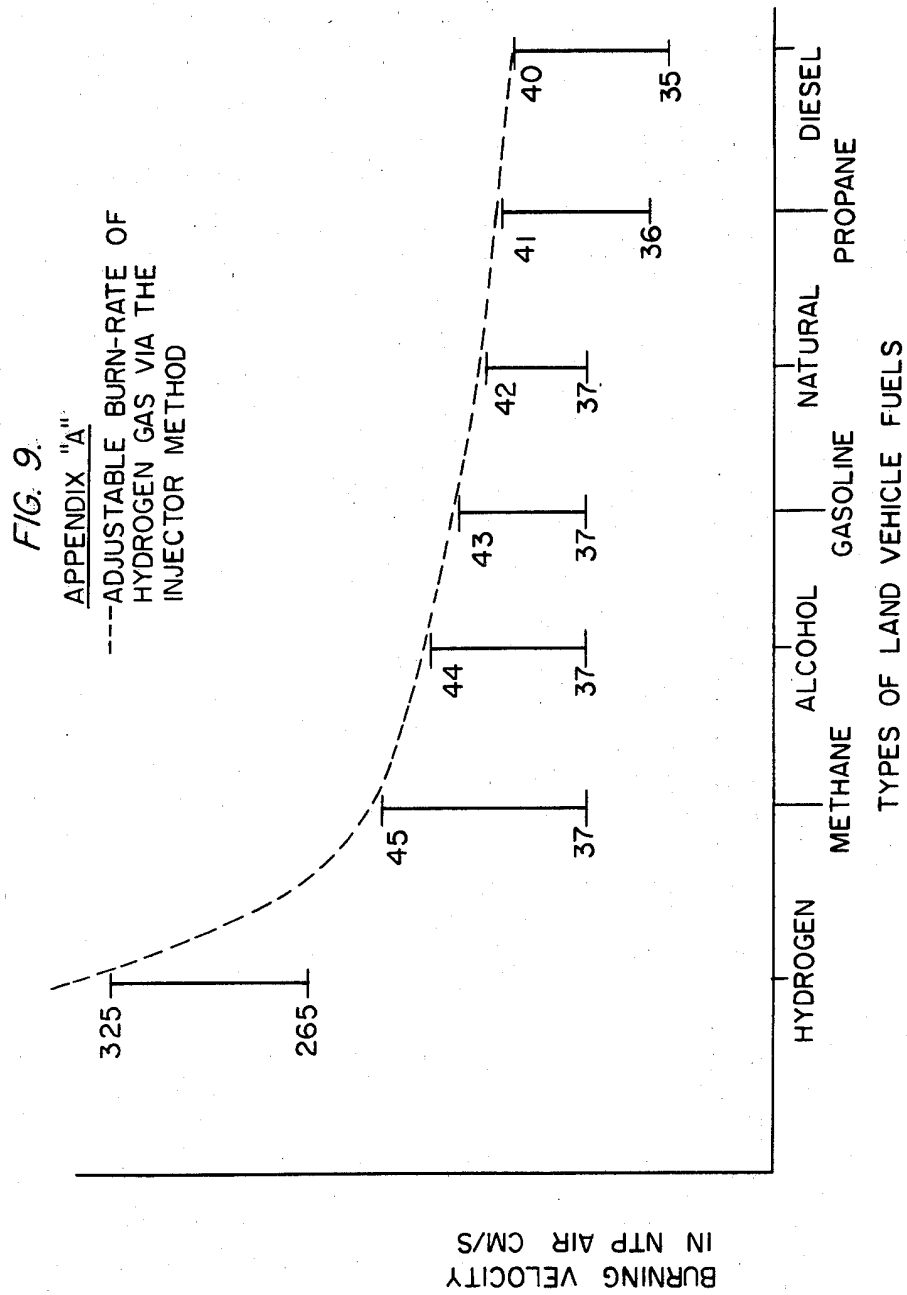


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## HYDROGEN GAS INJECTOR SYSTEM FOR INTERNAL COMBUSTION ENGINE

### CROSS REFERENCES AND BACKGROUND

There is disclosed in my co-pending U.S. patent application Ser. No. 802,807 filed Sept. 16, 1981 for a Hydrogen-Generator, a generating system converting water into hydrogen and oxygen gasses. In that system and method the hydrogen atoms are dissociated from a water molecule by the application of a non-regulated, non-filtered, low-power, direct current voltage electrical potential applied to two non-oxidizing similar metal plates having water passing there-between. The sub-atomic action is enhanced by pulsing the non-regulated and non-filtered direct current voltage. The apparatus comprises structural configurations in alternative embodiments for segregating the generated hydrogen gas from the oxygen gas.

In my co-pending patent application filed May 5, 1981, U.S. Ser. No. 262,744 now abandoned for Hydrogen-Airdation Processor, non-volatile and non-combustible gasses are controlled in a mixing stage with a volatile gas. The hydrogen airdation processor system utilizes a rotational mechanical gas displacement system to transfer, meter, mix, and pressurize the various gasses. In the gas transformation process, ambient air is passed through an open flame gas-burner system to eliminate gasses and other present substances. Thereafter the non-combustible gas-mixture is cooled, filtered for impurity removal, and mechanically mixed with a pre-determined amount of hydrogen gas. There results a new synthetic gas. The synthetic gas formation stage also volume meters and determines the proper gas-mixing ratio for establishing the desired burn-rate of hydrogen gas. The rotational mechanical gas displacement system in that process determines the volume-amount of synthetic gas to be produced.

The above-noted hydrogen airdation processor, of my co-pending application, is a multi-stage system having utility in special applications. Whereas the hydrogen generator system of my other mentioned co-pending application does disclose a very simple and unique hydrogen generator.

In my co-pending patent application Ser. No. 315,945, filed Oct. 18, 1981 there is disclosed a combustion system having utility in a mechanical drive system. Particularly in one instance to drive a piston in an automotive device. There is shown a hydrogen generator for developing hydrogen gas, and perhaps other non-volatile gasses such as oxygen and nitrogen. The hydrogen gas with the attendant non-volatile gasses are fed via a line to a controlled air intake system. The combined hydrogen, non-volatile gasses, and the air after inter-mixing are fed to a combustion chamber where it is ignited. The exhaust gasses of the combustion chamber are returned in a closed loop arrangement to the mixing chamber for the mixture of volatile and non-combustible gasses. Particular applications and structural embodiments of the system are disclosed.

### SUMMARY OF INVENTION

The system of the present invention in its most preferred embodiment is for a combustion system utilizing hydrogen gas; particularly to drive a piston in an automobile device. The system utilizes a hydrogen generator for developing hydrogen gas. The hydrogen gas and other non-volatile gasses are fed to a mixing chamber

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also having oxygen fed thereto. The mixture is controlled to regulate the burning temperature; that is, to lower the temperature velocity of the hydrogen gas to that of the commercial fuels. The hydrogen gas feed line to the combustion chamber includes a fine linear control gas flow valve. An air intake is the source of oxygen and it also includes a variable valve. The exhaust gasses from the combustion chamber are utilized in a controlled manner as the non-combustible gasses.

The hydrogen generator is improved upon to include a holding tank to provide a source of start-up fuel. Also, the hydrogen gas generator includes a switch to the power source operable from one position to another dependant upon a pressure sensing switch on the combustion chamber.

The simplified structure includes a series of one-way valves, safety valves, and quenching apparatus. The combination of apparatus comprises the complete assembly for converting the standard automobile engine from gasoline (or other fuels) to the hydrogen gas mixture.

### OBJECTS

It is accordingly a principal object of the present invention to provide a combustion system of gasses combined from a source of hydrogen and non-combustible gasses.

Another object of the invention is to provide such a combustion system that intermixes the hydrogen and non-combustible gasses in a controlled manner and thereby control the combustion temperature.

A further object of the invention is to provide such a combustion system that controls the fuel flow to the combustion chamber in a system and apparatus particularly adapted to hydrogen gas.

Still other objects and features of the present invention will become apparent from the following detailed description when taken in conjunction with the drawings in which:

### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a mechanical schematic illustration partly in block form of the present invention in its most preferred embodiment.

FIG. 2 is a block schematic illustration of the preferred embodiment of the hydrogen injector system of FIG. 1.

FIG. 3 is the fine linear fuel flow control shown in FIG. 1.

FIG. 4 is crosssectional illustration of the complete fuel injector system in an automobile utilizing the concepts of the present invention.

FIG. 5 is a schematic drawing in a top view of the fuel injector system utilized in the preferred embodiment.

FIG. 6 is a crosssectional side view of the fuel injector system in the present invention.

FIG. 7 is a side view of the fuel mixing chamber.

FIG. 8 is a top view of the air intake valve to fuel mixing chamber.

FIG. 9 is a comparison of the burning velocity of hydrogen with respect to other fuels.

### DETAILED DESCRIPTION OF INVENTION TAKEN WITH DRAWINGS

Referring to FIG. 1 the complete overall gas mixing and fuel flow system is illustrated together for utiliza-

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tion in a combustion engine particularly an engine utilized in an automobile.

With specific reference to FIG. 1, the hydrogen source 10 is the hydrogen generator disclosed and described in my co-pending application, supra. The container 10 is an enclosure for a water bath 2. Immersed in the water 2 is an array of plates 3 as further described in my co-pending application, supra. Applied to plates 3 is a source of direct current potential via electrical inlet 27. The upper portion 7 of the container 10 is a hydrogen storage area maintaining a predetermined amount of pressure. In this way for start up there will be an immediate flow of hydrogen gas. To replenish the expended water the generator provides a continuous water source 1. Thereafter, the generator is operable as described in the aforesaid patent application.

The safety valve 28 is rupturable upon excessive gas build-up. Whereas the switch 26 is a gas pressure switch to maintain a predetermined gas pressure level about a regulated low-volume.

The generated hydrogen gas 4 is fed from the one-way check valve 16 via pipe 5 to a gas mixing chamber 20, wherein the hydrogen gas is inter-mixed with non-combustible gasses via pipe line 9 from a source hereinafter described.

In the event one way valve 75 should fail and there be a return spark that might ignite the hydrogen gas 4 in the storage area 7 of hydrogen generator 10, quenching assembly 76 will quench the spark and prevent such ignition.

With particular reference to FIG. 2 the hydrogen gas via pipe line 5 and non-combustible gasses via pipe line 9 are fed to a carburator (air-mixture) system 20 also having an ambient air intake 14.

The hydrogen gas 4 is fed via line 5 through nozzle 11 in a spray 16 in to the trap area 46 of the mixing chamber 20. Nozzle 11 has an opening smaller than the plate openings in the quenching assembly 37, thereby preventing flash back in the event of sparking. The non-volatile gasses are injected into mixing chamber 20 trap area 47 in a jet spray 17 via nozzle 13. Quenching assembly 39 is operable much in the same manner as quenching assembly 37.

The ambient air is, in the preferred arrangement, the source of oxygen necessary for the combustion of the hydrogen gas. Further, as disclosed in the aforesaid co-pending application the non-volatile gasses are in fact the exhaust gasses in a closed loop system. It is to be understood that the oxygen and/or the non-combustible gasses can be from an independent source.

With continued reference to FIG. 2 the gas trap area 47 is a predetermined size. In that hydrogen is lighter than air, the hydrogen will rise and become entrapped in the area 47. The size of area 47 is sufficient to contain enough hydrogen gas for instant ignition upon start up of the combustion engine.

It will be noted that the hydrogen gas is injected in the uppermost region of the trap area 47. Hydrogen rises at a much greater velocity than oxygen or non-combustible gasses; perhaps three times or greater. Therefore, if the hydrogen gas entered the trap area 47 (mixing area) at its lowermost region the hydrogen gas would rise so rapidly that the air could not mix with the oxygen. With the structure shown in FIG. 2 of the trap area 47, the hydrogen gas is forced downwardly into the air intake 15. That is, the hydrogen gas is forced downwardly into the upwardly forced air and readily mixed therewith.

The ratio of the ambient air (oxygen) 14 and the non-combustible gas via line 9 is a controlled ratio and determined by the particular engine. Once the proper combustion rate is determined by the adjustment of valve 95 for varying the amount of the non-combustible gas and the adjustment of valve 45 for varying the amount of the ambient air, the ratio is maintained.

In a system wherein the non-combustible gasses are the exhaust gasses of the engine in a closed loop arrangement, and wherein the air intake is under the control of the engine, the flow velocity and hence the air/non-combustible mixture, is maintained by the acceleration of the engine.

The mixture of air with non-combustible gasses becomes the carrier for the hydrogen gas. That is, the hydrogen gas is superimposed on the air/non-combustible mixture. By varying the amount of hydrogen gas superimposed on the air/non-combustible mixture, the r.p.m. of the engine is controlled.

Reference is made to FIG. 3 illustrating precisely in a side view crosssection the fine linear fuel flow control 53. The hydrogen gas 4 enters chamber 43 via gas inlet 41. The hydrogen gas passes from chamber 43. The hydrogen gas passes from chamber 43 to chamber 47 via port or opening 42. The amount of gas passing from chamber 43 to chamber 47 is controlled by controlling the port opening 42.

The port opening is controlled by the insertion there through the linearly tapered pin 73. The blunt end of pin 73 is fixed to rod 71. Rod 71 passed by supporting O-ring 75, through opening 81 in housing 30, to manual adjustment mechanism 83.

The spring 49 retains the rod 71 in a fixed position relative to the pin 73 and opening 42. Upon actuating the mechanism 83, the pin 73 will recede from the opening 42 there by increasing the amount of gas passing from chamber 43 to chamber 47.

The stops 67 and 69 maintain spring 49 in its stable position. The position of the pin 73 in a fixed position relative to opening 42 is adjusted via threaded nuts 63 and 67 on threaded rod 61. That is, the threaded adjustment controls the idle speed or permits the minimum amount of gas to pass from chamber 43 to chamber 47 for continuous operation of the combustion engine.

Referring now to FIG. 8 there is illustrated the air adjustment control for manipulating the amount of air passing into the mixing chamber 20. The closure 21 mounted on plate 18 has an opening 17 on end 11 thereof. Slideably mounted over said opening 17 is a plate control 42. The position of the plate relative to the opening 17 is controlled by the position of the control rod 19 passing through a grommet 12 to control line. In event of malfunction that may cause combustion of gasses in mixing chamber 20, release valve 24 will rupture.

With reference now to FIG. 4, in the event hydrogen gas 4 should accumulate in the mixing chamber 20 to excessive pressure, an escape tube 36 connected to a port 34 on the automobile hood 32 permits the excess hydrogen gas to safely escape to the atmosphere. In the event of a malfunction that may cause combustion in the mixing chamber 20, the pressure relief valve 33 will rupture expelling hydrogen gas without combustion.

In the constructed arrangement of FIG. 1, there is illustrated a gas control system that may be retrofitted to an existing automobile internal combustion engine without changing or modifying automobile's design parameters or characteristics.

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The flow of the hydrogen volatile gas is, of course, critical; therefore, there is incorporated in line 5 a gas flow valve 53 (FIG. 1) to adjust the hydrogen flow. Gas flow valve is described in detail with reference to FIG. 3.

The intake air 14 may be in a carburetor arrangement with an intake adjustment 55 that adjusts the plate 42 opening and also more fully described with reference to FIG. 8.

To maintain constant pressure in hydrogen gas storage 7 in the on-off operation of the engine, the gas flow control valve is responsive to the electrical shut-off control 33. The constant pressure permits an abundant supply of gas on start up and during certain periods of running time in re-supply.

The switch 33 is in turn responsive to the vacuum control switch 60. During running of the engine vacuum will be built up which in turn leaves switch 33 open by contact with vacuum switch 60 through lead 60a. When the engine is not running the vacuum will decrease to zero and through switch 60 will cause electrical switch 33 to shut off cutting off the flow of hydrogen gas to the control valve 53.

As low-voltage direct current is applied to safety valve 28, solenoid 29 is activated. The solenoid applies a control voltage to the hydrogen generator exciter 3 via terminal 27 through pressure switch 26. As the electrical power activates electric solenoid 29, hydrogen gas is caused to pass through flow adjustment valve 16 and then outlet pipe 5 for utilization. The pressure differential hydrogen gas output to gas mixing chamber 20 is for example 30 lbs. to 15 lbs. Once hydrogen generator 10 reaches an optimum gas pressure level, pressure switch 26 shuts off electrical power to the hydrogen exciters. If the chamber pressure exceeds a predetermined level, the safety release valve 28 is activated disconnecting the electrical current and thereby shutting down the entire system for safety inspection.

With particular reference now to FIG. 6 there is illustrated the fuel injector system in a side crosssectional view and to FIG. 5 in a top view. The structural apparatus incorporated in the preferred embodiment comprises housing 90 having air intakes 14a and 14e. The air passes through filter 91 around the components 14b and 14c and then to intake 14d of the mixing chamber 20. The hydrogen enters via line 5 via quenching plates 37 and into the mixing chamber 20. The non-volatile gasses pass via line 9 to the quenching plates 39 and into the mixing chamber 20.

FIG. 7 illustrates the mechanical arrangement of components comprising the overall structure of the mixing chamber 20 and shown independently in the other figures.

Returning to FIG. 1 there is illustrated the non-volatile gas line 9 passing through mixture pump 91 by engine pulley 93. Valve 95 controls the rate of flow.

Also driven by pulley 93 is pump 96 having line 85 connected to an oil reservoir 92 and valve 87 and finally to mixing chamber 20. As a practical matter, such as in a non-oil lubricated engine, lubricating fluid such as oil 81 is sprayed in the chamber 20, via oil supply line 85 for lubrication.

There has been several publications in the past year or so delving on the properties of Hydrogen gas, its potential use, generating systems, and safety. One such publication is "Selected Properties of Hydrogen" (Engineering Design Data) issued February 1981 by the National Bureau of Standards.

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These publications are primarily concerned with the elaborate and costly processes for generating hydrogen. Equally so, they are concerned with the very limited use of hydrogen gas because of its extremely high burning velocities. This in turn reflects the danger in the practical use of hydrogen.

With reference to the graph of the Appendix A, it is seen that the burning velocities of alcohol, propane, methane, gasoline, natural gas, and diesel oil are in the range of minimum 35 to maximum 45. Further, the graph illustrates that the burning velocity of hydrogen gas is in the range of 265 minimum to 325 maximum. In simple terms in the order of 7.5 times the velocity of ordinary commercial fuels.

Because of the hydrogen gas unusually high burning velocity, hydrogen gas has been ruled out, by these prior investigators as a substitute fuel. Further, even if an engine could be designed to accommodate such high velocities, the danger of explosion would eliminate any thoughts of commercial use.

The present invention, as above described, has resolved the above-noted criteria for the use of hydrogen gas in a standard commercial engine. Primarily, the cost in the generation of hydrogen gas, as noted in the aforementioned co-pending patent applications, is most minimal. Water with no chemicals or metals is used. Also, as note in the aforementioned co-pending patent applications, is the reduction in the hydrogen gas velocity. These co-pending applications not only teach the reduction in velocity, but teach the control of the velocity of the hydrogen gas.

In the preferred embodiment, practical apparatus adapting the hydrogen generator to a combustion engine is described. The apparatus linearly controls the hydrogen gas flow to a mixing chamber mixing with a controlled amount of non-combustible gas oxygen, hence, the reduction in the hydrogen gas velocity. The reduction in the hydrogen gas velocity makes the use of hydrogen as safe as other fuels.

In more practical terms the ordinary internal combustion engine of any size or type of fuel, is retrofitted to be operable with only water as a fuel source. Hydrogen gas is generated from the water without the use of chemicals or metals and at a very low voltage. The burning velocity of the hydrogen gas has been reduced to that of conventional fuels. Finally, every component or step in the process has one or more safety valves or features thereby making the hydrogen gas system safer than that of conventional automobiles.

In the above description the terms non-volatile and non-combustible were used. It is to be understood they are intended to be the same; that is, simply, gas that will not burn.

Again, the term storage has been used, primarily with respect to the hydrogen storage area 7. It is not intended that the term "storage" be taken literally—in fact it is not storage, but a temporary holding area. With respect to area 7, this area retains a sufficient amount of hydrogen for immediate start-up.

Other terms, features, apparatus, and the such have been described with reference to a preferred embodiment. It is to be understood modifications and alternatives can be had without departing from the spirit and scope of the invention.

I claim:

1. A combustion system comprising:  
a hydrogen/oxygen generator,

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a housing having a water reservoir for retaining natural water therein and a gas collection chamber maintaining a preset volume of gas under pressure, a pair of similar non-oxidizing plates positioned in said water reservoir, a direct current voltage source connected to said plates to disassociate the hydrogen atoms and oxygen atoms from said water molecules; and a gas mixing chamber, means connecting the hydrogen gas from said hydrogen source to said mixing chamber, a fuel linear control valve in said hydrogen gas connecting means for regulating the hydrogen gas flow to said mixing means, said fuel linear control valve including a port and a linear element in said port regulating the opening therein, a source of non-volatile gas; means connecting the non-volatile gas from said non-volatile source to said mixing chamber, ambient air intake means connected to the input of said mixing chamber for combining air with said hydrogen gas and said non-volatile gasses, a gas burner having said controlled amount of hydrogen gas combined with said non-volatile gas and ambient air from said air-intake means fed thereto.

2. The combustion system of claim 1 wherein said ambient air-intake means further comprises a housing having a variably positioned plate valve thereover for controlling the amount of air-intake to said mixing chamber.

3. The combustion system of claim 1 further comprising a housing in said hydrogen gas connecting means having intake and outlet means and a port intermediate therein and wherein said linear element is positioned in said port.

4. The combustion system of claim 1 wherein said linear element is a tapered structure.

5. The combustion system of claim 4 further including a rod mechanism connected to said tapered structure, and means for varying said tapered structure relative to said port.

6. The combustion system of claim 1 wherein said mixing chamber comprises a quenching apparatus at its hydrogen gas input and a quenching apparatus at its non-volatile gas input.

7. The combustion system of claim 1 wherein said gas mixing chamber comprises at its uppermost region a trap area; and wherein said hydrogen gas connection to said mixing chamber is in the uppermost region of said trap area.

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8. The combustion system of claim 7 wherein said ambient air intake is in the lowermost region of said trap.

9. The combustion system of claim 8 wherein said ambient air intake means comprises a control valve and wherein said non-combustible gas intake means comprises a control valve, said valves adjustable to permit predetermined ratio mixtures of air and non-combustible gas to enter said mixing chamber.

10. The combustion system of claim 8 wherein said ambient air intake provides a hydrogen release for excess hydrogen in said trap area in said combustion chamber.

11. The combustion system of claim 7 wherein said control valve connected to said burner is a pressure regulated valve.

12. The combustion system of claim 7 further comprising housing means for enclosing said mixing chamber, a first opening in said housing for the intake of air, and a second opening in said housing for the release of hydrogen gas that may be entrapped therein.

13. The combustion system of claim 1 further comprising a control valve connected to said burner and said hydrogen gas fuel connection means for controlling the flow of gas during on and off operation of said combustion system.

14. The combustion system of claim 1 wherein said hydrogen gas generator upper enclosed area further comprises a pressure relief valve operable upon the hydrogen gas retained therein exceeding a pre-determined amount.

15. The combustion system of claim 14 wherein said hydrogen gas generator further comprises a sensing switch connected to said electrical source and said pressure relief valve and operable to disconnect said electrical source when said combustion system is inoperable.

16. The combustion system of claim 1 and wherein said means for connecting said hydrogen gas to said mixing chamber comprises one-way check valve.

17. The combustion system of claim 1 and wherein said means for connecting said hydrogen gas to said mixing chamber further comprises a quenching assembly.

18. The combustion system of claim 1 wherein said gas burner is an internal combustion engine, and wherein said source of non-volatile gasses is the exhaust for gasses of said engine.

19. The combustion system of claim 18 further comprising an oil source and an oil spray connected thereto and to said mixing chamber.

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**United States Patent** [19]

Carr et al.

[11] Patent Number: **4,458,634**[45] Date of Patent: **Jul. 10, 1984****[54] INTERNAL COMBUSTION ENGINE WITH HYDROGEN PRODUCING DEVICE HAVING WATER AND OIL INTERFACE LEVEL CONTROL**

[76] Inventors: **Edwin R. Carr**, 5211 Astaria; **Donald L. Carr**, 5406 Hillside, both of Amarillo, Tex. 79109

[21] Appl. No.: **465,769**

[22] Filed: **Feb. 11, 1983**

[51] Int. Cl.<sup>3</sup> ..... **F02B 43/08; C25B 15/02; C25B 9/00; C25B 15/08**

[52] U.S. Cl. .... **123/3; 123/DIG. 12; 123/536; 204/229; 204/270; 204/274; 204/278; 204/306; 204/308**

[58] Field of Search ..... **204/229, 306, 308, 129, 204/275-278, 274, 270; 123/DIG. 12, 3, 536**

**[56] References Cited****U.S. PATENT DOCUMENTS**

1,754,009	4/1930	Cage	204/306
2,136,469	11/1938	Sauer	204/306
2,336,205	12/1943	Willauer	204/306 X
3,704,222	11/1972	Kusovsky et al.	204/306
3,849,285	11/1974	Prestridge	204/306 X
4,033,851	7/1977	Oros	204/306 X
4,271,793	6/1981	Valdespino	123/DIG. 12
4,361,474	11/1982	Shoaf et al.	123/DIG. 12

**FOREIGN PATENT DOCUMENTS**

2344648 10/1977 France ..... 204/229

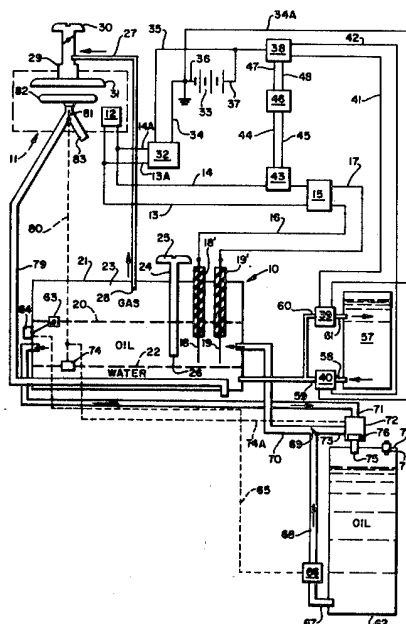
Primary Examiner—Donald R. Valentine

Attorney, Agent, or Firm—Warren H. Kintzinger

**[57] ABSTRACT**

A control system for maintaining a desired water level range from electrodes spaced thereabove in a layer of oil where alternating current discharge occurs from

electrode down to and through water to another electrode, with the electrical discharge occurring between electrodes disposed at all times in the hydrocarbon oil layer. With the situs of reaction being confined to the oil and the interstitial boundry between the oil and water, dangerous conditions of hydrogen generation are generally obviated over most state-of-the-art methods of producing hydrogen with a highly efficient production process. Hydrocarbon gases and vapors are also produced from the oil with a cracking process occurring to some extent incumbent with the A C discharge from the electrodes through the oil to the water. This has also been found to gradually upgrade the quality of the oil remaining while some is at the same time consumed in the system. The hydrocarbon gases and vapors are also subject to hydrogen enrichment during the ongoing process. In a system with hydrogen produced being used along with hydrocarbon gases and vapors produced from the oil to run an internal combustion engine A C power developed by an A C generator driven by the engine flows through a current transformer to a step transformer increasing the A C voltage applied to the electrodes used in the process. A C current being sensed develops a D C signal, through a rectifier, proportional to the A C power current being fed to the electrodes. The D C signal is passed through control circuitry to activate individual relay controls when the signal level falls below a desired level and rises above a desired level. This is effective to, at preset signal levels, activate a pump or open a drain cock for removing water from the tank or another pump (or reversal of a pump) to feed water back to the tank to maintain the water level in the tank within a desired range consistent with desired rates of hydrogen generation through the process.

**29 Claims, 2 Drawing Figures**

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FIG. 1

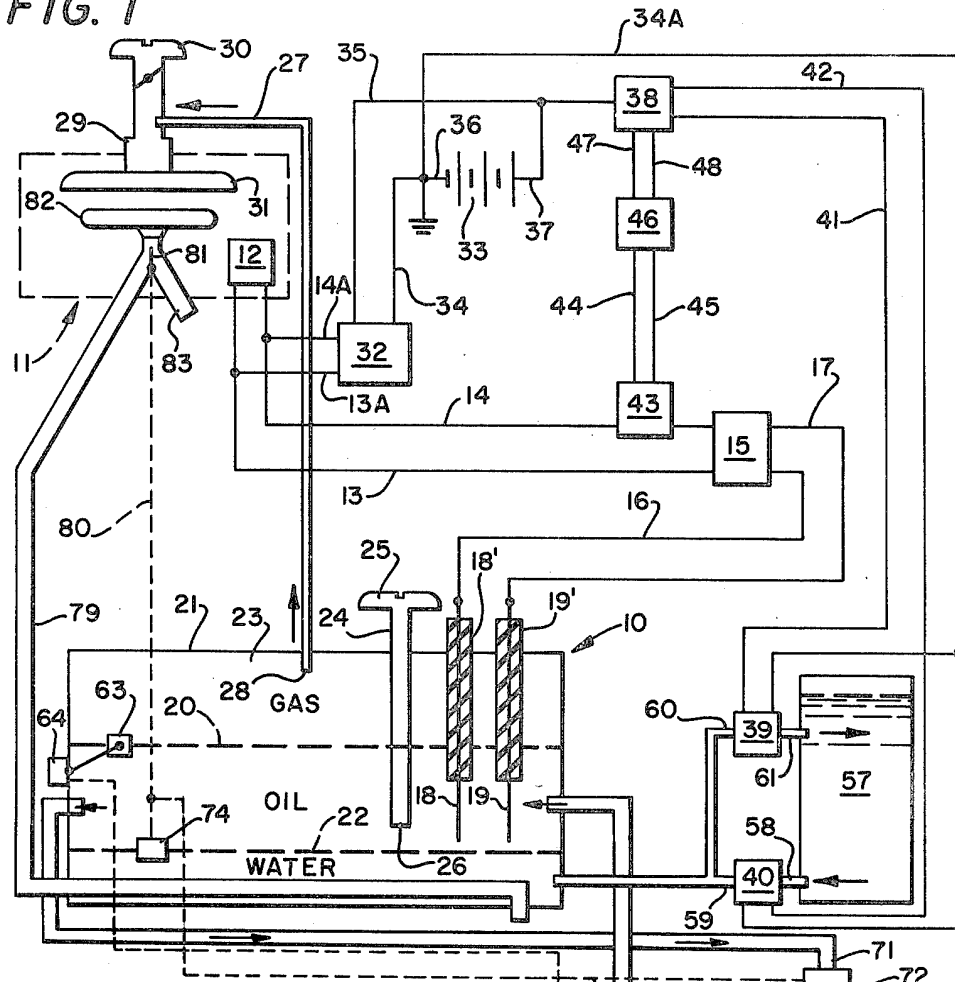
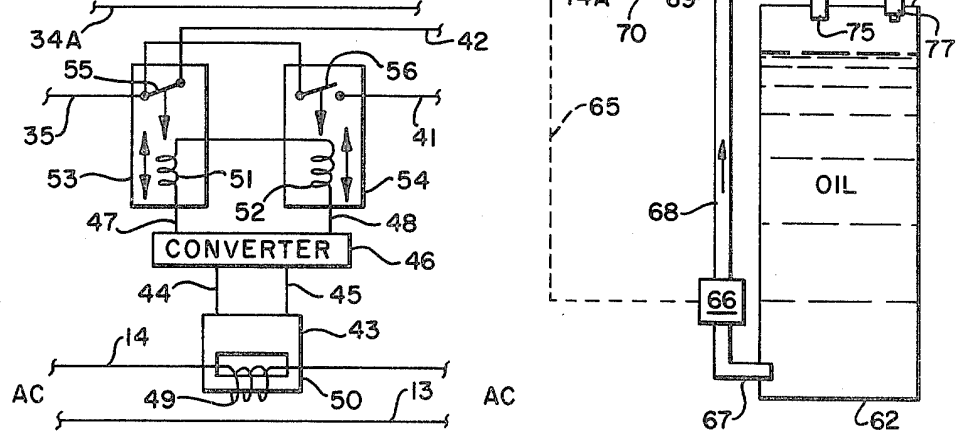


FIG. 2



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## INTERNAL COMBUSTION ENGINE WITH HYDROGEN PRODUCING DEVICE HAVING WATER AND OIL INTERFACE LEVEL CONTROL

This invention relates in general to the electrodecomposition of water and cracking of oil to produce gaseous hydrogen along with hydrocarbon gases and, more particularly, to production of hydrogen and hydrogen enriched hydrocarbon gases in a container holding oil and water and a closed space for gas above oil and water layers with AC discharge from electrodes in the oil layer down to and through the water from one electrode to another with a water level control activated for water removal or water addition by predetermined levels of AC power current flow.

The process for producing hydrogen and other gases, such as set forth in U.S. Pat. No. 4,233,132 and entitled "Method and Apparatus for Producing Hydrogen", of which we are two of the co-inventors, produces hydrogen in varying amounts consistent with AC power supplied and the application. With AC electric power essential to the process, power control is required which, if the power is 60 cycle AC supplied by a power company, may be provided by standard controls. However, in adapting the process to fuel a conventional internal combustion engine there are various control and electric power supply considerations. In remote locations standard AC electric power may not be available, and in fueling an engine with hydrogen gas produced by the process precise process control is important. Standard controls have not been found that would yield the control accuracy required in the operating electromagnetic arc discharge state encountered in the process. The electromagnetic discharge arc voltage runs in the range of 1,000 to 2,000 volts with arc discharge initiating potential peaking as high as 8,000, even 10,000 volts-voltage variations and levels detrimental to many electronic controls. It is important that the water level control system be able to provide the close control required even though the AC power signal varies in frequency and that the control have high level and low level set points to operate relays and/or pumps or valves. A controlling factor in varying the AC current is the water level to electrode spacing that is varied through addition of water or removal of water. As crude oil is used in the process, water in the oil not used by the process may be removed to maintain the water level within the control limits required. Where herebefore electrodes were adjustable to compensate wear or water level changes the improved water level control automatically compensates for electrode wear and eliminates the need for adjustable electrodes.

It is, therefore, a principal object of this invention to provide wear and oil interface level spacing control from electrodes regardless of the state of electrode erosion in an electrodecomposition of water hydrogen production and hydrocarbon gas production oil cracking process.

Another object is to achieve the desired water level control through sensed levels of AC power current flow.

A further object is to provide such a water level control with an upper level control set point and a lower level control set point.

Still another object is to provide such amperage current flow span between control upper level and lower

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level set points as to allow for small variations in AC power line current.

Another object is to provide such a water level control not subject to pump water level control actuation by current surges of short duration through a built-in time delay in the control circuit.

Features of the invention useful in accomplishing the above objects include, in a water and oil interface level to electrode end space control of a system for electrodecomposition of water to produce hydrogen along with hydrocarbon gas, produced with oil cracking, fueling an engine, an AC power current level sensed control for activating an upper water level control for removal of water and for activation of a lower water level control for adding of water. AC power developed by an AC generator driven by the engine flows through a current transformer to a step transformer increasing the AC voltage applied to the electrodes used in the process. The AC current being sensed develops a DC signal, through a rectifier, proportional to the AC power current being fed to the electrodes. This DC signal is applied through control circuitry to activate respective relay controls when the signal level rises above a desired level, and when the signal level falls below a desired level. This acts, at preset signal levels, to activate a pump or open a drain cock for removing water from the tank or another pump (or reversal of a pump) to feed water back to the tank to maintain the water level in the tank within a desired range consistent with desired rates of hydrogen generation through the process.

A specific embodiment of the water and oil interface level to electrode spacing control in a hydrogen and hydrocarbon gas production process presently regarded as the best mode of carrying out the invention is illustrated in the accompanying drawing.

### IN THE DRAWING

FIG. 1 represents a block schematic diagram of a hydrogen and hydrocarbon gas production unit fueling an engine and the water level to electrode spacing control system therefor; and,

FIG. 2, a partial block schematic showing AC power current sensing to high set point relay and low set point relay for controlled activation of high level and low level water pumps.

### REFERRING TO THE DRAWING

The hydrogen and hydrocarbon gas production unit 10 is shown in FIG. 1 to be connected for feeding gaseous fuel and hydrocarbon vapors to an engine 11 useful to any number of purposes such as a stationary power plant for powering any number of things (detail not shown). A generator 12, driven by engine 11 in a conventional manner, develops AC power fed through lines 13 and 14 to step up transformer 15 that has high voltage output connections through lines 16 and 17 to electrodes 18 and 19, respectively, the exposed portions of which, generally below the insulated feed mounts 18' and 19', are in a layer of oil 20. The hydrogen gas production unit 10 has a tank 21 containing a lower layer of water 22, the layer of oil 20 above the water and a closed space 23 for gas above the layer of oil 20. The gap spacing between the bottom ends of electrodes 18 and 19 and the upper surface of the water layer 22 is important in the electrodecomposition of water to produce gaseous hydrogen where with AC power current flow decreasing with increased spacing between the



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electrodes 18 and 19 and the water layer 22. Obviously, the level of AC power flow in discharge through the oil 20 to the water layer 22 controls the degree of oil cracking and hydrocarbon gas production.

The hydrogen and hydrocarbon gas production unit 10 is provided with an air inlet pipe 24 extending from an air cleaner 25 above the tank 21 to an outlet end 26 well within the layer of oil 20 to dispel inlet air into the oil layer 20. Air and gas fuel (mostly hydrogen along with hydrocarbon gas) is fed through pipe 27 from open end 28 within closed space 23 to valve and carburetor structure 29 on engine 11 through which additional air may be drawn from air filter 30 and delivered to inlet manifold 31 for engine 11. The AC power output of generator 12 is also connected through lines 13A and 14A to AC to DC rectifier 32 that rectifies the AC to provide 12-volt DC for charging 12-volt battery 33 through lines 34 and 35 to battery terminals 36 and 37, respectively, with line 34 being the ground connection line for the system. The positive DC power line 35 is connected to control head 38 where subject to set level relay control power circuits are completed for power activation of high level pump 39 and low level pump 40 through DC power lines 41 and 42, respectively, when a level limit is sensed.

The current transformer 43 senses the AC power flow being delivered through line 14 to step up transformer 15 and develops a proportional low power AC signal fed through lines 44 and 45 to rectifier 46 (AC to DC inverter) supplying a like proportioned DC signal, low in the milliamp range, to control head 38 through DC lines 47 and 48.

Referring also to the partial block schematic showing of FIG. 2, power line 14 is shown to include a coil 49 wound around a ferrite circuit loop 50 of the current transformer 43. The DC leads 47 and 48 out of AC to DC converter 46 are shown to be series connected through current sensitive, adjustable, series connected coils 51 and 52 of relays 53 and 54 that have, respectively, a normally closed relay switch 55 and a normally open switch 56. The normally closed switch 55 of relay 53 is activated by the current flow at a preset current flow sensing level to open, and below that level to close, for the application of power through line 42 to low level pump 40 to pump water from water supply tank 57 through water pipe 58 to the pump 40 and from the pump 40 through line 59 to the water layer 22. This raises the upper surface of the water layer and decreases the gap between the low ends of electrodes 18 and 19 to thereby provide progressive increase in current flow to and through the electrodes 18 and 19, hydrocarbon material of oil layer 20 and the intervening water layer 22. A further increase in current flow through the series connected coils 51 and 52 results in closing of switch 56 to apply positive DC power through line 41 to pump 39 in order to withdraw water from water level 22 in tank 21 through pipe 59 and pipe 60 to the pump 39 and on through pipe 61 back to water reservoir tank 57.

These two lower level and upper level adjustable set points in activation of the switches of relays 53 and 54 allow the system to be operated at a predetermined current level range spanning several amps that may be adjusted for specific applications with typically, in one instance, a 10-amp span being provided between the two respective relay actuation points to allow for small variations in line current. An inherent or built-in time delay in the control circuitry allows for current surges of short duration without activation of either pump. As

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the AC power current level rises above the set point power is supplied to the high pump 39 for removal of water from the hydrogen and hydrocarbon gas generation process tank 21. When the AC power current falls below the low set point the normally closed switch 55 of relay 53 closes to power pump 40 in order to add water to the water layer 22 in tank 21. Obviously this operates at a very effective water level to electrode gap control to thereby maintain proper power flow through the system in developing gas for fueling the engine 11 in system operation. This control of water level eliminates any need for adjusting of electrodes since it is a self-adjusting water level control to maintain water to electrode spacing within the desired range provided in the span associated with the sensed level operation of the two relays 53 and 54 in series or parallel.

It should be noted that pumps 39 and 40, either one or both, could in some installations be valves that permit exhaust flow to a lower water level outlet and that the other pump could be a valve that opens to admit water under pressure from a water pressure source to the water level 22 in tank 21.

It should also be noted that the pump drives of pumps 39 and 40 could be AC power drives instead of the DC power drive system shown by circuitry and motor equipment known to those skilled in the art. Furthermore, the frequency of AC developed by generator 12 can vary through a considerable range without having an adverse effect on the hydrogen and hydrocarbon gas process and control therefor provided herein.

Oil from oil supply tank 62 is used to supply oil to the layer of oil 20 as oil is consumed in the gas generating process as demand is indicated by float 53 and float control 64 that is connected in a conventional manner (indicated by dashed line 65) to oil supply pump 66. A pipe line 67 connection from the bottom of oil supply tank 62 to pump 66 and pipe line 68 to valve 69 and pipe line 70 feed make up oil to the layer of oil 20 at the electrode end of tank 21 when pump 66 is activated to pump oil. An oil withdrawal pipe line 71 extends from the opposite end of tank 21 from the electrode end to an oil circulation pump 72 from which outlet pipe line 73 connects to valve 69 for circulation of oil on through pipe line 70 back to the electrode end of tank 21. Temperature sensor 74 that may be located in either the oil or water near water oil surface in tank 21 and connected for activating the circulation pump 72 in a conventional manner as through a connection indicated by a dashed line 74A when the temperature sensed reaches a predetermined level. The circulation pump is also equipped with a pipe flow line 75 connection to the oil supply tank 62 to, as controlled by temperature control valve 76, divert some of the oil pumped by pump 72 to supply tank 62. It is of interest to note, particularly where crude oil is used in the process, the cracking action with the arc discharge of the process upgrades the oil to a more valuable higher price oil so, even though some oil is consumed in the overall system with hydrocarbon gases and vapors being used to help run a motor along with hydrogen generated the improvement in the otherwise crude oil so processed can go toward covering the cost of oil consumption. An air vent valve 77 in the top 78 of oil storage or supply tank 62 prevents pressure differential damage to the tank 62 as oil is drawn from the tank or pumped into the tank. The temperature control valve 76 is generally set to divert oil back to the supply tank 62 only when the temperature of oil being recirculation pumped by pump 72 is

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above a predetermined level in order that oil circulated through the oil layer 20 in tank 21 be readily maintained at a desired process temperature level without having to heat massive supplies of oil in a storage and supply tank 62. The valve 69 is a self adjusting valve permitting flow of oil from oil feed pump 66 or from circulation pump 72 or balance of oil flow from both pumps when they are simultaneously pumping.

Since the process produces more fuel in gas and vapor form at higher temperature a heat exchanger engine exhaust pipe line 79 is passed through the water layer 22 portion of process tank 21. The temperature sensor 74 is connected through a conventional connection as indicated by dash line 80 for varying valve 81 in balanced controlled diversion of hot exhaust gases from the engine exhaust manifold 82 between direct exhaust pipe 83 and the pipe line 79 extended through tank 21. This helps, for example, in countering disassociation cooling of the water as hydrogen is released from oxygen in the electro-disassociation process.

Testing of the system was conducted using a 534 cubic Ford engine running at 1,750 r.p.m. pulling a 70 horse power load with the process adding approximately an additional 15 horse power to the engine load. Oil consumption was, with proper controls, lowered into approximately the 2.5 to 4 gallon per hour consumption rate at approximately 50 hours into a run. Further, starting with 39 gravity oil with recycling of oil passed through the process tank 21 returned to large tank storage gravity of the stored oil was lowered beneficially to 36 gravity in approximately 90 hours of running.

Whereas the invention is herein described with respect to a preferred embodiment thereof, it should be realized that various changes may be made without departing from the essential contribution made by the teachings hereof.

We claim:

1. In a water layer and oil layer interface level to electrode end spacing control system useful in oil cracking hydrocarbon gas generation combined with electrodecomposition of water hydrogen production: container means for containing, a layer of water at the bottom, a layer of oil above the layer of water, and a space for containing gas above the layer of oil; electrode means positioned in said container entrained primarily in the layer of oil with an electrode means end to water layer gap; AC power source means; AC circuit means interconnecting said AC power source means and said electrode means for feeding AC power through said electrode means, the gap and water within the container; AC power current sensing means sensing current level flow through said AC circuit means; electric power control means responsive to a predetermined AC current level flow; water flow control means in the form of fluid flow impetuous means and conduit means with a line from a water source with power activation means for controlling the level of water within said container; and AC power source means connected to and through said electric power control means to said water flow control means for controlling the water level and thereby the electrode means end to water layer gap in response to predetermined AC current level flow with AC current flow varying inversely with variation in electrode means end to water layer gap spacing.

2. The water layer and electrode end spacing control system of claim 1, wherein said electrode means is a

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plurality of electrodes including at least one pair of electrodes with said AC power source means connected for AC power discharge current flow back and forth from one electrode through the electrode to water level gap, through water to and through the gap of the other electrode of said pair of electrodes.

3. The water layer and electrode end spacing control system of claim 2, wherein said AC power current sensing means is a current transformer output connected to said electric power control means.

4. The water layer and electrode end spacing control system of claim 3, wherein said electric power control means is switch means responsive to AC power current level for switch actuation control of the power activation means of said water flow control means.

5. The water layer and electrode end spacing control system of claim 4, wherein said water flow control means includes pump means.

6. The water layer and electrode end spacing control system of claim 5, wherein said pump means is a pump and water flow structure controlled for pumping water into said container when the water level is low and the AC power current flow sensed is below a first preset level, and for pumping water from said container when the water level is high and the AC power current flow sensed is above a preset level.

7. The water layer and electrode end spacing control system of claim 6, wherein said pump and water flow structure is connected to a reservoir tank.

8. The water layer and electrode end spacing control system of claim 6, wherein said pump and water flow structure includes a first pump for pumping water out of said container; and a second pump for pumping water into said container.

9. The water layer and electrode end spacing control system of claim 6, wherein there is a current span between control upper level and lower level set points allowing for relatively small variations in AC power line current.

10. The water layer and electrode end spacing control system of claim 6, wherein there is control level actuation time delay to prevent pump water level control actuation by current surges of short duration or current drops of short duration.

11. The water layer and electrode end spacing control system of claim 4, wherein there is an AC to DC converter in the current transformer output connection to said electric power control means.

12. The water layer and electrode end spacing control system of claim 11, wherein adjustable level relay means is used as said switch means.

13. The water layer and electrode end spacing control system of claim 12, wherein the adjustable level relay means is an upper level set point adjustable level relay and a lower level set adjustable level relay.

14. The water layer and electrode end spacing control system of claim 13, wherein there is a current span between control upper level and lower level set points allowing for relatively small variations in AC power line current.

15. The water layer and electrode end spacing control system of claim 13, wherein there is control level actuation time delay to prevent pump water level control actuation by current surges of short duration or current drops of short duration.

16. The water layer and electrode end spacing control system of claim 4, wherein said power source is an AC generator connected via control circuitry to and

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through said electric power control means to said water flow control means.

17. The water layer and electrode end spacing control system of claim 16, wherein said AC power source means is said AC generator, and with said AC generator driven by an engine connected for using hydrogen and hydrocarbon gases drawn from said container means as engine fuel.

18. The water layer and electrode end spacing control system of claim 17, wherein said switch means is relay means.

19. The water layer and electrode end spacing control system of claim 18, wherein said control circuitry from said AC generator includes an AC to DC converter.

20. The water layer and electrode end spacing control system of claim 19, wherein said control circuitry also includes a system battery connected in the control circuitry for charge input from said AC to DC converter.

21. The water layer and electrode end spacing control system of claim 1, wherein said circuit means inter-connecting said AC power source means and said electrode means includes a step up transformer.

22. The water layer and electrode end spacing control system of claim 21, wherein said AC power current sensing means is positioned for sensing AC power current flow between said AC power source means and said step up transformer.

23. The water layer and electrode spacing control system of claim 1, wherein oil supply storage means is connected through oil supply piping means to said container means; oil layer surface level sensing and control means; and oil flow control means with power activation means connected for control by said oil layer surface level sensing and control means for controlling the level of oil within said container.

24. The water layer and electrode end spacing control system of claim 23, also including an oil circulation system with an oil piping system connected for withdrawing oil from said container and returning oil to said container, returning oil to said oil supply storage means, and moving oil from said oil supply storage means; and oil movement driving means in said oil piping system including said oil flow control means.

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25. The water layer and electrode end spacing control system of claim 24, wherein said oil flow control means includes pump means connected for actuation by said oil layer surface level sensing and control means; said oil movement driving means includes a pump in said oil circulation system; temperature sensing control means in said container connected to said pump to control on and off oil moving driving actuation of said pump; and control means diverting portions of oil pumped by said pump to said oil supply storage means.

26. The water layer and electrode end spacing control system of claim 25, wherein said AC power source means is an AC generator connected via control circuitry to and through electric power control means to water flow control means; an internal combustion engine is connected for using hydrogen and hydrocarbon gases drawn from said container means as engine fuel; and said internal combustion engine being provided with an exhaust system with heat exchange means positioned in said container means.

27. The water layer and electrode end spacing control system of claim 26, wherein said exhaust system includes controllable exhaust flow diverting means; temperature sensing control means in said container connected to said controllable exhaust flow diverting means for control flow of hot exhaust gases through said heat exchange means in heating water and oil in said container means.

28. The water layer and electrode end spacing control system of claim 1, wherein said AC power source means is an AC generator connected via control circuitry to and through electric power control means to water flow control means; an internal combustion engine is connected for using hydrogen and hydrocarbon gases drawn from said container means as engine fuel; and said internal combustion engine being provided with an exhaust system with heat exchange means positioned in said container means.

29. The water layer and electrode end spacing control system of claim 28, wherein said exhaust system includes controllable exhaust flow diverting means; temperature sensing control means in said container connected to said controllable exhaust flow diverting means for control flow of hot exhaust gases through said heat exchange means in heating water and oil in said container means.

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# United States Patent [19]

## Watanabe

[11] Patent Number: **4,508,064**[45] Date of Patent: **Apr. 2, 1985**[54] **INTERNAL COMBUSTION ENGINE OF HYDROGEN GAS**[75] Inventor: **Kenji Watanabe**, Kagoshima, Japan[73] Assignee: **Katsuji BABA**, Kagoshima, Japan; a part interest[21] Appl. No.: **425,915**[22] Filed: **Sep. 28, 1982**[30] **Foreign Application Priority Data**

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 Feb. 3, 1982 [JP] Japan ..... 57-14819  
 Feb. 3, 1982 [JP] Japan ..... 57-14820

[51] Int. Cl.<sup>3</sup> ..... **F02B 75/12**[52] U.S. Cl. .... **123/1 A; 123/DIG. 12; 123/525**[58] Field of Search ..... **123/1 A, DIG. 12, 25 R, 123/25 A, 25 D, 25 P, 525**[56] **References Cited****U.S. PATENT DOCUMENTS**

2,183,674 12/1939 Erren ..... 123/1 A

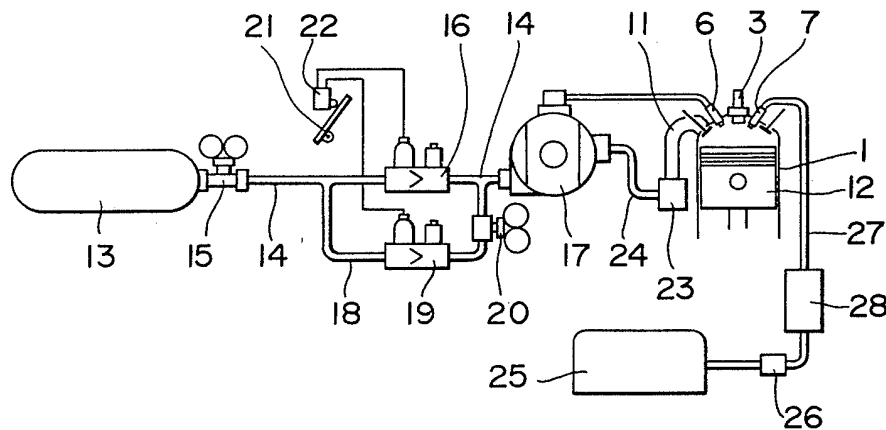
3,696,795 10/1972 Smith et al. .... 123/DIG. 12  
 3,983,882 10/1976 Billings ..... 123/DIG. 12  
 4,178,882 12/1979 Anderson et al. .... 123/DIG. 12

**FOREIGN PATENT DOCUMENTS**

231000 3/1925 United Kingdom ..... 123/27 G  
 2059501 4/1981 United Kingdom ..... 123/25 D

*Primary Examiner*—E. Rollins Cross*Attorney, Agent, or Firm*—Frishauf, Holtz, Goodman & Woodward[57] **ABSTRACT**

A hydrogen gas internal combustion engine provided with a hydrogen gas jet nozzle and water spray jet nozzle in the combustion chamber to directly jet hydrogen gas and the water spray therein. The sprayed water is instantly vaporized to steam by igniting the hydrogen gas thereby utilizing the combustion/explosion energy of the hydrogen gas and the steam energy generated from the vaporization of the steam in a combination to obtain mechanical dynamic energy.

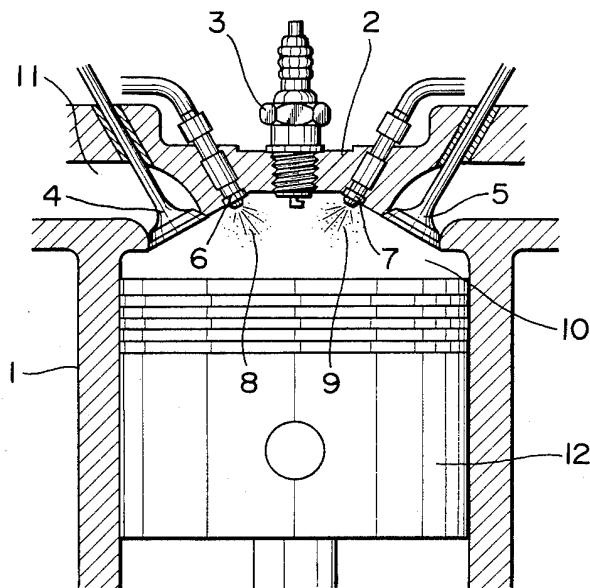
**7 Claims, 6 Drawing Figures**

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FIG. 1



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FIG. 2

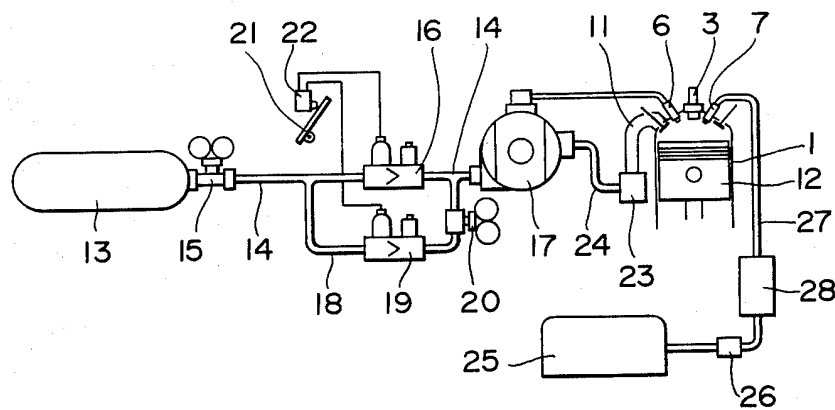
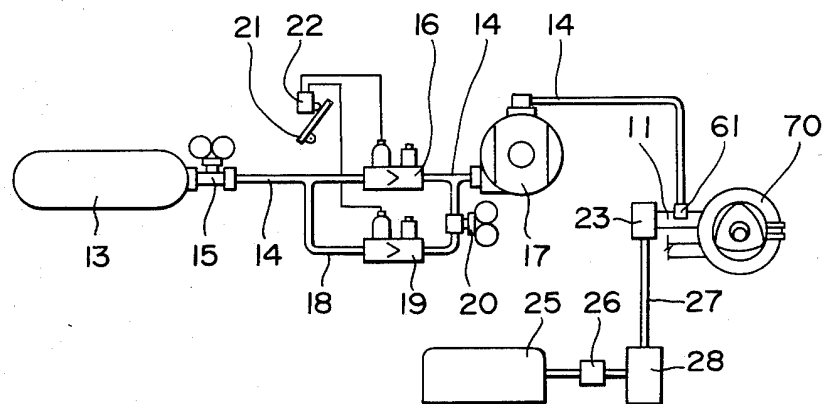
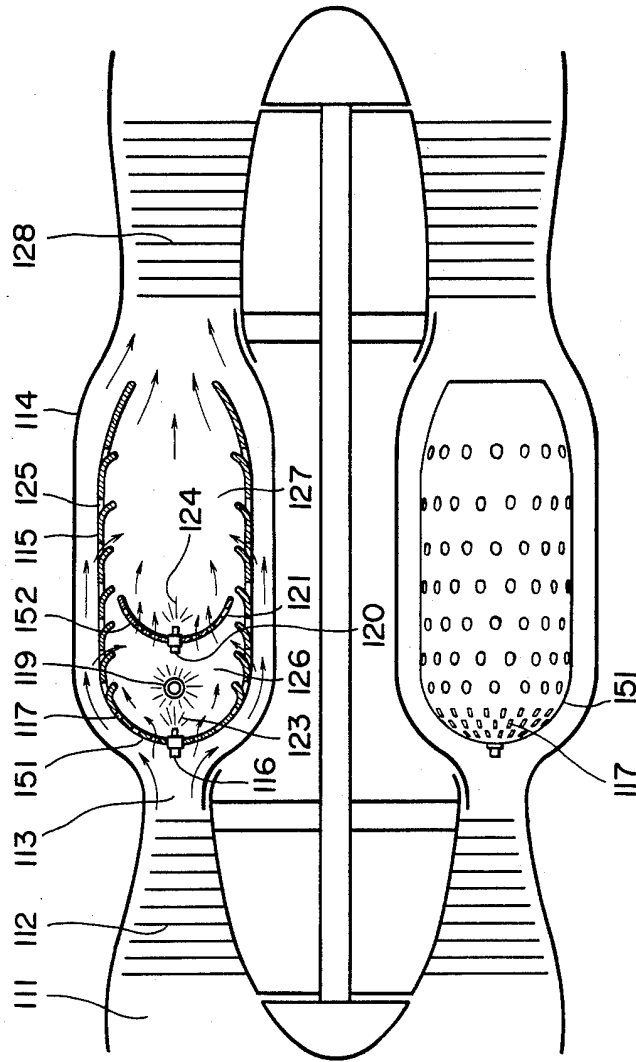


FIG. 3



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FIG. 4



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FIG. 5

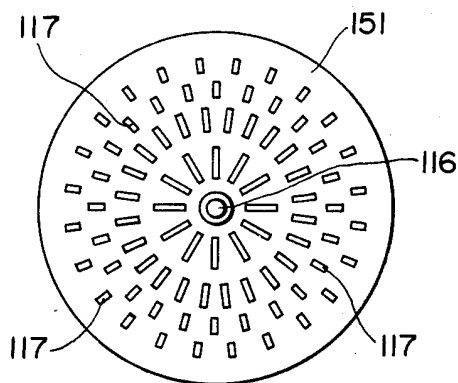
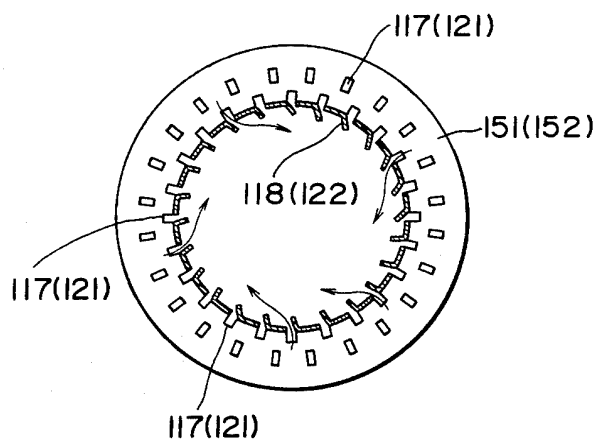


FIG. 6





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## INTERNAL COMBUSTION ENGINE OF HYDROGEN GAS

### BACKGROUND OF THE INVENTION

This invention relates to an internal combustion engine which uses hydrogen gas as the fuel for thermal energy source and is capable of effectively converting the explosive energy generated by the combustion of hydrogen gas into mechanical kinetic energy.

As is well known in the art, since hydrogen gas engines are more advantageous than gasoline engines in that they have a better mileage and cause less pollution, various tests products have been manufactured. Test engines so far manufactured are, however, mostly far less practical in terms of output, engine configuration and weight, economy, etc. when compared with conventional type engines of petroleum fuels, and the development thereof has come to a deadlock.

The fundamental reason why these trial hydrogen engines have not yet reached the stage of practical use is that all these attempts were made to directly convert the combustion/explosion energy of hydrogen gas into mechanical kinetic energy as is done in conventional gasoline engines.

When hydrogen gas is viewed as a fuel for obtaining mechanical dynamic energy, its combustion rate is by far the greater than that of gasoline, and as a result the conversion of its combustion/explosion energy into mechanical dynamic energy becomes very low. The unconverted thermal energy which remains in the combustion chamber becomes accumulated and causes abnormal temperature rises in the parts which constitute the combustion chamber and adjacent parts thereof. This in turn hampers a smooth supply of hydrogen gas into the combustion chamber and the timely ignition as required, whereby proper engine driving becomes impossible.

Actual problems encountered in an internal combustion engine using hydrogen gas as the fuel is that although during idling when the fuel supply is limited, the engine can be kept running by a mixture diluted with the air, and a high load operation with an increased fuel supply will cause the premature ignition due to the increase in the hydrogen concentration. Thus, back fires and knocking are easily caused and the pressure is rapidly increased.

In order to overcome this problem, Billings and Daimler-Benz have proposed to supply hydrogen gas which is mixed with the water into the combustion chamber in order to lower the temperature of the combustion gas as well as the temperature of overheated parts. Previous attempts of this sort have succeeded in preventing the back fires and knocking to a certain extent. But since they must limit the maximum output to about 60% of the output obtained by gasoline engines in order to reduce the heat capacity produced by combustion and to prevent abnormal combustion, the output capacity cannot be sufficiently increased.

An object of the present invention is to overcome the problems heretofore encountered in hydrogen gas engines and to provide a feasible engine which is capable of increasing the efficiency in converting the combustion/explosion energy of hydrogen gas into mechanical dynamic energy and which can be put into practical use.

Another object of the present invention is to provide a hydrogen gas engine capable of preventing premature

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ignition, back fires and knocking even under a high load operation by restricting the thermal energy generated by the combustion and explosion of hydrogen gas by means of the water spray introduced into the combustion chamber concurrently with the gas supply.

Still another object of the invention is to provide a hydrogen gas engine with a higher efficiency in conversion of energy into mechanical dynamic energy by vaporizing the water spray which has been introduced in the combustion chamber into steam by the heat of combusting hydrogen gas and utilizing the effect of combined forces of hydrogen gas and the steam.

Yet another object of the present invention is to provide a hydrogen gas engine capable of a smooth operation both under the high and low loads by means of separate channels, each of which supplying hydrogen gas in an amount suitable for either the high or low load operation respectively.

### SUMMARY OF THE INVENTION

The hydrogen gas engine according to the present invention is characterized in that hydrogen gas and the water supply are not mixed in advance but are directly introduced into the combustion chamber via separate nozzles. Hydrogen gas and the water spray are jetted into the combustion chamber simultaneously or at slightly staggered timings. As the compressed hydrogen gas is ignited by the ignition plug in the combustion chamber, the thermal energy by the combustion of hydrogen gas is directly converted into mechanical dynamic energy. At the same time, a portion of the thermal energy causes the water spray in the combustion chamber to instantly vaporize into steam, whereby explosive thermal energy of hydrogen gas and steam will become combined and converted into mechanical dynamic energy.

Whereas the combustion rate of hydrogen gas itself is high in the hydrogen gas engine of the present invention, the rate at which the water spray vaporizes by the combustion of the gas is relatively slower than the combustion rate of gasoline engines, explosion/combustion of hydrogen gas and vaporization of the water spray take place in the same combustion chamber as a series of related actions. As a result, the conversion of these energies into mechanical dynamic energy may take place in a manner similar to that in gasoline engines. The hydrogen gas engine according to the present invention is thus made capable of effectively utilizing the thermal energy of hydrogen gas which has otherwise been exhausted when hydrogen gas alone was subjected to combustion, and increasing the resultant mechanical dynamic energy.

Further, as the water to be supplied in the combustion chamber together with hydrogen gas is not pre-mixed with the gas, but is directly and separately supplied in the form of spray, the spray gives rise to steam energy in the combustion chamber which is maintained at a high temperature and pressure because of the quickly burning hydrogen gas. The steam helps to improve the conversion rate of thermal energy of hydrogen gas combustion into mechanical dynamic energy. The supply of the water spray also acts to reduce the thermal energy which remains unconverted in the combustion chamber, so that the temperature rise in the parts constituting the chamber and adjacent parts can be restricted. The hydrogen gas engine according to the present invention is thus advantageous in its smooth supply of

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hydrogen gas into the combustion chamber and the timely ignition.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view of the cylinder of a piston type reciprocating engine to which the hydrogen gas engine of the present invention is applied.

FIG. 2 shows the fuel supply system of the hydrogen gas engine shown in FIG. 1.

FIG. 3 shows the fuel supply system of a rotary engine to which the hydrogen gas engine of the present invention is applied.

FIG. 4 is a sectional view of a gas turbine to which the hydrogen gas engine of the present invention is applied.

FIG. 5 is a front view of the semi-spherical nozzle cover which constitutes the frontal part of the combustion cylinder.

FIG. 6 shows the nozzle cover shown in FIG. 5 sectioned in part.

### DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a sectional view of the cylinder in a reciprocating engine to which the present invention is applied. As is shown, the cylinder 1 has a cylinder head 2 which is provided with an ignition plug 3, an inlet valve 4 and an exhaust valve 5 together with a nozzle 6 for pressurized jetting of hydrogen gas and a nozzle 7 for spraying the water that are provided respectively for supplying the hydrogen gas 8 and the water spray 9 into the combustion chamber 10. The nozzles 6 for pressurized jetting of the hydrogen gas and the water spraying nozzle 7 jet the hydrogen gas 8 and the water spray 9 into the combustion chamber 10 from respective sources (not shown) either simultaneously or at slightly staggered timings.

Hydrogen gas 8 and the water spray 9 are fed during the compression stroke as in the ordinary gasoline engines where a piston 12 moves upward and the inlet valve 4 and the exhaust valve 5 are both closed. Jetting is respectively cut off just before the piston 12 reaches the upper dead end, when the compressed hydrogen gas is ignited by the ignition plug 3. The thermal energy generated by combustion of ignited hydrogen gas is directly converted into mechanical dynamic energy. At the same time, the water spray is converted into steam instantly in the combustion chamber which is maintained at a high temperature and pressure due to the quickly burning hydrogen gas, whereby explosive thermal energy of hydrogen gas and steam energy are combined and become a mechanically dynamic energy to press down the piston 12. The exhaust strokes and the inlet strokes following said explosion strokes are the same as those in the ordinary gasoline engine.

FIG. 2 shows the fuel supply system of an automobile engine of reciprocating type to which the present hydrogen gas engine is applied. Hydrogen gas 8 is pressurized and directly jetted into the cylinder 1 from a container 13 via a gas supply channel 14 without passing a carburetor 23. The channel 14 supplies hydrogen gas at a pressure of about 5 kgf/cm<sup>2</sup> by means of a pressure control means 15 provided at the mouth of the container 13. There are provided at an intermediate point in the channel a check valve 16 and a regulator 17 which reduce the pressure and regulate the flow rate. Hydrogen gas passes through the regulator 17 and flows at a low pressure of about 0.5 kgf/cm<sup>2</sup> into the nozzle 6 for

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pressurized jetting. The nozzle 6 pressurizes and jets the gas at a predetermined pressure into the cylinder 1. The channel 14 is provided on both sides of the check valve 16 with a by-pass 18 which supplies low pressure gas during a low load operation and which by-passes the check valve 16. The by-pass 18 is provided with a check valve 19 and a pressure control means 20; the pressure control means 20 lowers the pressure of hydrogen gas sent from the container 13 from about 5 kgf/cm<sup>2</sup> to about 0.1 kgf/cm<sup>2</sup>. Hydrogen gas thus lowered in the pressure to about 0.1 kgf/cm<sup>2</sup> is sent to the regulator 17 via the by-pass 18 during a low load operation such as idling, when a limit switch 22 provided at an accel pedal 21 closes as the pedal 21 is released and causes the check valve 19 to open on the by-pass 18 and at the same time, it also causes the check valve 16 on the supply channel 14 to close. Since the predetermined pressure set at the regulator 17 is greater than the pressure at which the gas flows in from the by-pass 18, said gas at a low pressure of about 0.1 kgf/cm<sup>2</sup> proceeds intact to the nozzle 6 for pressurizing and jetting the gas, where the gas is pressurized to the predetermined pressure and jetted into the cylinder 1.

When the accel pedal is stepped on to bring about a high load operation, said switch 22 opens to cause the check valve 19 on the by-pass 18 to close and the check valve 16 on the supply channel 14 to open at the same time, whereby the gas from the container 13 is sent to the regulator 17 to be pressurized to about 0.5 kgf/cm<sup>2</sup> and sent to the nozzle 6 where the gas is further pressurized to the predetermined value before being fed into the cylinder 1.

The amount of gas 8 to be supplied in accordance with the changes in the rate of engine rotation can be controlled by adjusting the flow rate at the regulator 17 by means of a vacuum pipe 24 connecting a carburetor 23 and the regulator 17 in accordance with the degree of opening the throttle valve of the carburetor 23.

As is described above, by providing the by-pass 18 which can supply hydrogen gas at a pressure lower than the predetermined pressure and suitable for a low load operation into the supply channel 14, a high load operation which is effected by means of said supply channel 14 can be made smoothly, and moreover, a low load operation such as idling can also be maintained smooth without trouble by supplying low pressure gas via the said by-pass 18. Experiments using a reciprocating engine with 1800 cc capacity and a rotary engine of commercial automobiles proved that application of the present invention could ensure a smooth operation not only during a low speed running but also during a higher speed running of up to 120 kg/h.

The water spray 9 to be sprayed into the cylinder 1 together with hydrogen gas 8 is supplied from a tank 25 (at ambient temperature; i.e., "room" or "normal" temperature) via a pipe 27 provided with a feed pump 26 by regulating the supply amount in correspondence with the changing rate of engine rotation by means of a spray pump 28 which is controlled in accordance with the engine rotation.

FIG. 3 shows the fuel supply system of a rotary engine to which the present invention is applied. In this case, the supply system for hydrogen gas 8 is identical with said reciprocating engine mentioned above, but the supply system for the water spray is somewhat different. In the rotary engine, the water is supplied from the tank 25 to the carburetor 23 via a feed pump 26, and said carburetor 23 atomizes and sprays the water into a rotor

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housing 70 via the inlet port 11 together with the air. On the other hand, hydrogen gas 8 is jetted into the inlet port 11 via a nozzle 61 provided on the inlet port 11. It should be noted that the hydrogen gas 8 and the water spray 9 are introduced into the inlet port 11 via separate channels. In other words, hydrogen gas 8 is supplied in the inlet port provided at immediate anterior of the rotor housing 70 via a separate channel 14, just before the mixture of the water spray and the air is supplied into the rotor housing 70. This is the fundamental difference of the present invention from the conventional type in which hydrogen gas, the water and the air are mixed in advance before being supplied into the cylinder.

FIG. 4 shows an embodiment of the present invention using a gas turbine. In the drawing, the reference number 111 represents an air inlet port, 112 a compressor, 113 an inlet port for the pressurized air, 114 a turbine casing, and 115 a combustion cylinder. The tip of the combustion cylinder 115 constitutes a semi-spherical nozzle cover 151. At the center inside a front nozzle cover 151 is provided a nozzle 116 for jetting hydrogen gas. As shown in FIGS. 5 and 6, a plurality of apertures 117 for deflecting and introducing the air are provided around the nozzle 116 for discharging hydrogen gas. These apertures are provided radially from the nozzle 116 and have guide fins 118 therein so that the compressed air around the nozzle cover 151 can be deflected toward its inside when the said air is introduced into the combustion cylinder 115.

An ignition plug 119 is provided behind the nozzle 116 for hydrogen gas, and a rear nozzle cover 152 which is semi-spherical in shape like the front nozzle cover 151 is provided behind the ignition plug 119. The rear nozzle cover 152 is also provided radially about a nozzle 120 for the water spray with a plurality of apertures 121 having guide fins at the inside for deflecting and introducing the combustion gas.

Hydrogen gas 123 and the water spray 124 are jetted from the nozzles 116 and 120 respectively while the air compressed by the compressor 112 is being fed from the turbine casing 114 toward the combustion cylinder 115 via the apertures 117 for deflecting and introducing the air which are provided at the front nozzle cover 151 and via the air holes 125 provided at the side of the combustion cylinder. When the ignition plug 119 placed behind the hydrogen gas nozzle 116 is actuated at this state, hydrogen gas 123 burns continuously at a higher pressure in the front combustion zone 126 located behind the hydrogen gas nozzle 116. At the same time, the water spray 124 is introduced in the zone located behind the rear nozzle cover 152 which is located behind the combustion zone 126 and contacted with combusting hydrogen gas 123 to be vaporized in the rear combustion zone 127 located behind the rear nozzle cover 152. Thus, the combustion energy of hydrogen gas and the steam power of the water spray are combined in the combustion cylinder to continuously produce expansion energy.

In other words, since the compressed air to be introduced in the combustion cylinder 115 is directed rotatingly and spirally toward the inner periphery of the front combustion zone 126 in the cylinder from the apertures 117 (for deflecting and introducing the air) provided at the front nozzle cover 151, a negative pressure zone is formed behind the nozzle 116 in said combustion zone 126 as the center of the vortex. This promotes jetting of hydrogen gas 123 and its diffusion,

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thereby expanding the area of combustion and improving the inflammability.

The combustion gas produced by the explosion in the front combustion zone 126 enters in vortex into the rear combustion zone 127 through the apertures 121 for guiding the gas on the rear nozzle cover 152 which separates the primary combustion gas and vaporizes the water 124 sprayed into said zone 127. The steam thus produced imparts expansive energy to the combustion gas coming into the rear combustion zone 127 through the apertures 121 on the nozzle cover 152 and from the side of the cover. As for the generation of the steam energy in the rear combustion zone 127, the water spray coming from the nozzle 120 can be effectively diffused and the area where the steam is formed may be expanded as the combustion gas enters in vortex from the apertures 121. The high temperature gas which is caused by a combination of the combustion energy produced in the zone 127 and the steam power due to vaporization of the water is transferred to the rear of the combustion cylinder 115 and is subsequently supplied to a power turbine 128 while being cooled by the air supplied from the air holes 125 at the rear of the said cylinder.

In this turbine which embodies the present invention, the area where the high temperature gas is formed is divided into two parts: the front combustion zone 126 where the combustion gas is produced by hydrogen gas 123; the rear combustion zone 127 where the steam power is produced by the water spray 124 to be contacted with the said combustion gas. This enables supply of the water spray sufficient to produce the steam power in the combustion cylinder 115 which is to be added to the high temperature gas produced by the combustion of hydrogen gas. If the water spray and hydrogen gas are mixed in advance and supplied at the same time, the jet pressure of hydrogen gas would obstruct the water spray in such a way that the particle size of the water spray cannot be reduced sufficiently enough, and thus the steam power which is to impart sufficient expansive force to the combustion gas cannot be generated.

As has been described above, the present invention can effectively convert the combustion/explosion energy of hydrogen gas into mechanical dynamic energy by combining the steam energy, and therefore assures a hydrogen gas engine to be put into practical use as a new power source which has been considered difficult heretofore.

What we claim is:

1. In a hydrogen gas fueled internal combustion engine, the improvement comprising:

a hydrogen gas jet nozzle provided in a combustion chamber of the engine to directly jet hydrogen gas as fuel into the combustion chamber;

a source of water at ambient or room temperature; and

a water spray jet nozzle coupled to said water source, said water spray jet nozzle being provided in said combustion chamber, separately and independently of said hydrogen gas jet nozzle, to directly jet a spray of said ambient or room temperature water into said combustion chamber substantially simultaneously with the jetting in of the hydrogen gas; the air in said combustion chamber being compressed so that the water sprayed into said combustion chamber is instantly vaporized to steam by igniting of the hydrogen gas jetted into said combustion

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chamber, thereby utilizing the combustion/explosion energy of the hydrogen gas and the steam energy generated from the vaporization of the steam in combination to obtain mechanical dynamic energy.

2. The hydrogen gas fueled internal combustion engine of claim 1, wherein said internal combustion engine is a piston-type reciprocating internal combustion engine having at least one cylinder and a cylinder head closing said cylinder, and wherein said hydrogen gas jet nozzle and said water spray jet nozzle are provided in said cylinder head.

3. The hydrogen gas fueled internal combustion engine of claim 1, wherein said internal combustion engine is a rotary engine having a combustion chamber and a rotor rotatably mounted in said combustion chamber, said combustion chamber having an inlet port, said hydrogen gas jet nozzle being provided in said inlet port for introducing hydrogen gas just before the mixture of said water spray and air is introduced into said combustion chamber via said inlet port.

4. The hydrogen gas fueled internal combustion engine of any one of claims 1, 2, or 3, further comprising a hydrogen gas supply channel coupled between a hydrogen gas container and said combustion chamber, said hydrogen gas supply channel including a low pressure hydrogen gas supply by-pass means for closing said hydrogen gas supply channel under low load operating conditions of said engine and for supplying said hydrogen gas to said combustion chamber at a pressure lower than the supply pressure in said hydrogen gas supply channel.

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5. The hydrogen gas fueled internal combustion engine of claim 1, wherein said internal combustion engine is a gas turbine engine having a cylinder defining a combustion chamber, the tip of said combustion chamber comprising a semi-spherical front nozzle cover having at its center said hydrogen gas jet nozzle, a rear nozzle cover being arranged inside said combustion chamber and having at its center said water spray jet nozzle, whereby continuous flowing gas in said combustion chamber is combined with steam energy generated by vaporization of the water spray to produce mechanical dynamic energy.

6. The hydrogen gas fueled internal combustion engine of claim 5, wherein said front and rear nozzle covers respectively are provided with apertures arranged radially around the respective nozzles for guiding air, said nozzle covers each further having guide fins for deflecting and dispersing compressed air inside said apertures at a given deflection angle.

7. The hydrogen gas fueled internal combustion engine of claim 7, further comprising a semi-spherical front nozzle cover and a rear nozzle cover arranged in said combustion chamber, said front nozzle cover having said hydrogen gas jet nozzle mounted thereto and said rear nozzle cover having said water spray jet nozzle mounted thereto, said nozzle covers respectively being provided with apertures arranged radially around the respective nozzles for guiding air, and said nozzle covers each further having guide fins for deflecting and dispersing compressed air inside said apertures at a given deflection angle.

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# United States Patent [19]

## Olivera

[11] Patent Number: **4,528,947**[45] Date of Patent: **Jul. 16, 1985**[54] **SOLAR OXY-HYDROGEN VEHICLE**[75] Inventor: **Wallace Olivera, Enfield, Conn.**[73] Assignee: **Uni-Energy Systems, Inc., Hartford, Conn.**[21] Appl. No.: **551,865**[22] Filed: **Nov. 15, 1983**

### Related U.S. Application Data

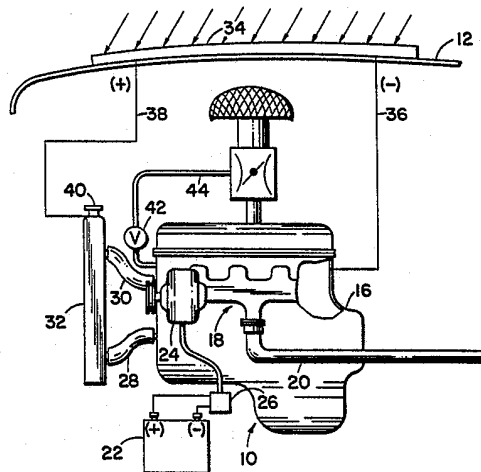
[63] Continuation-in-part of Ser. No. 319,042, Mar. 10, 1982, abandoned.

[51] Int. Cl.<sup>3</sup> ..... **F02B 43/00**[52] U.S. Cl. .... **123/3; 123/DIG. 12; 204/DIG. 4**[58] Field of Search ..... **123/1 A, 3, DIG. 12; 180/65.1, 65.3; 204/129, DIG. 4**[56] **References Cited**

### U.S. PATENT DOCUMENTS

4,141,425 2/1979 Treat ..... 180/65.3  
4,246,080 1/1981 Shinn ..... 123/34,271,793 6/1981 Valdespino ..... 123/3  
4,302,217 11/1981 Teitel ..... 123/3*Primary Examiner*—William A. Cuchlinski, Jr.  
*Attorney, Agent, or Firm*—McCormick, Paulding & Huber[57] **ABSTRACT**

An electrolysis unit for producing hydrogen and oxygen gases is formed by the cooling system of an internal combustion engine wherein the engine casing forms one of the electrodes and produces one of the hydrogen and oxygen gases and the radiator forms the other of the electrodes and produces the other of the gases. The electrolyte used in the electrolysis unit includes a hydride for absorbing and storing hydrogen produced by the electrolysis process and for releasing hydrogen when thermally activated. An array of solar cells is integrated into the body panels of the vehicle wherein the engine is located and is connected to the engine and radiator for supplying current to the electrolysis unit for producing the hydrogen and oxygen gases.

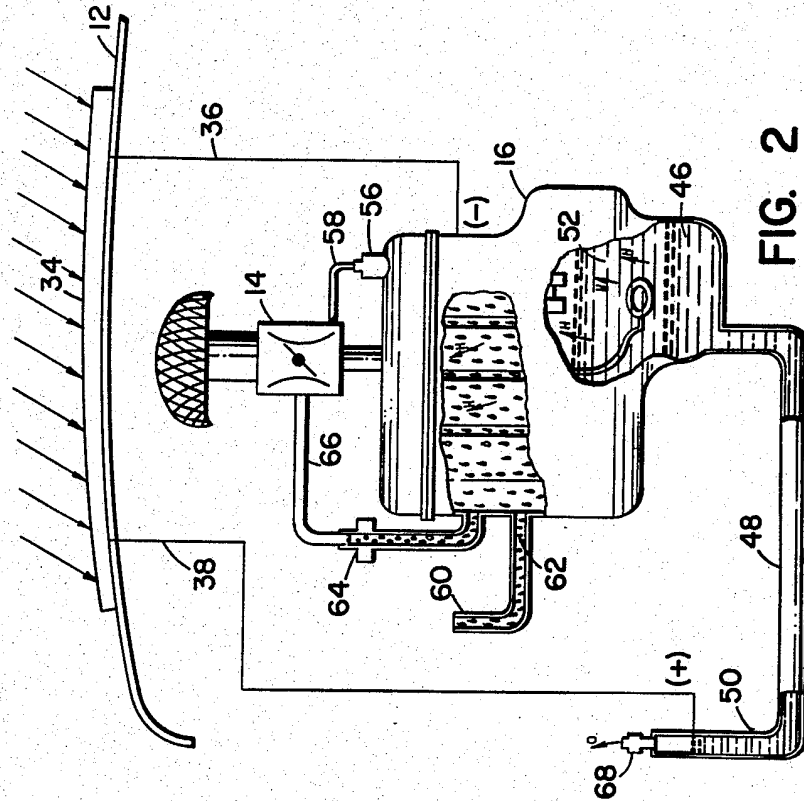
**10 Claims, 4 Drawing Figures**



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Sheet 2 of 4

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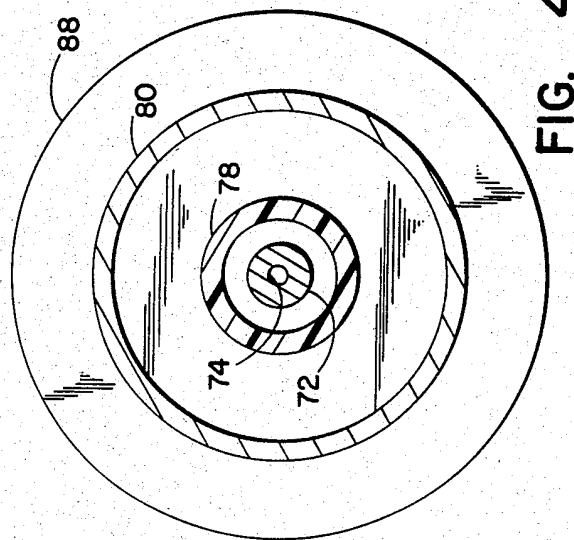




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**FIG. 4**

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**SOLAR OXY-HYDROGEN VEHICLE****CROSS REFERENCE TO RELATED APPLICATIONS**

This application is a C.I.P. of my application Ser. No. 319,042, filed Mar. 10, 1982 and entitled SOLAR OXY-HYDROGEN VEHICLE now abandoned.

**BACKGROUND OF THE INVENTION**

The present invention relates to vehicles of the type having a fuel burning engine, such as an internal combustion engine, in which the combustion process is improved through a solar-powered electrolysis unit that supplements the fuel and air mixture with hydrogen gas.

It is well known in the art to use hydrogen gas to facilitate the combustion of fuels in a fuel burner such as an internal combustion engine. However, certain of the drawbacks and limitations present in many previous approaches for generating and using hydrogen gas are overcome by the present invention.

U.S. Pat. No. 1,379,077, issued May 24, 1921 to Blumenberg, shows the generation of hydrogen and oxygen gases using an electrolysis unit in an automobile. The hydrogen and oxygen gases produced are passed through heavy hydrocarbon fuels where the fuel is physically and chemically modified by the hydrogen. The excess hydrogen gas is fed to a carburetor along with the modified fuel to enhance the fuel-air mixture to allow combustion of the hydrocarbon fuel. However, Blumenberg does not provide storage for any excessively produced hydrogen.

U.S. Pat. No. 4,302,217, issued Nov. 24, 1981 to Teitel, shows a system using a metal hydride to supply hydrogen gas when heated and a microcavity hydrogen storage supply to provide hydrogen gas to regenerate the metal hydride hydrogen supply when the metal hydride is depleted of hydrogen. In addition, the microcavity hydrogen storage supply requires periodic replacement with a freshly charged microcavity hydrogen component. Thermal controls are used to control the heating and cooling of the microcavity storage supply and the metal hydride to regulate the rate of discharge of hydrogen.

U.S. Pat. No. 4,271,793, issued June 9, 1981 to Valdespino, describes an internal combustion engine in which the fuel-air mixture is supplemented by the hydrogen and oxygen gases from an electrolysis unit. The unit is energized by the electrical generating system driven by the engine and the unit is only operative when the engine is running. Large amounts of current are required to produce the preferred amount of hydrogen and oxygen gases and consequently, the unit must be cooled by the engine coolant to dissipate the large amounts of heat generated to prevent electrolyte boil-off. The unit is also further pressurized to minimize boil-off.

The present invention provides an improved oxy-hydrogen fuel burning vehicle in which the electrolysis unit is aided by solar cells to generate supplemental gases that are stored while the vehicle is not in use. Another feature of the present invention eliminates the need for a conventional cooling system associated with the fuel burning engine because heat generated by the combustion and electrolysis processes is absorbed by the electrolyte to enhance the formation of hydrogen and oxygen gases. Still another feature of the invention

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is the design of the electrolysis unit which minimizes heat generated during electrolysis.

Additional features and advantages of the present invention will become apparent from the following written description and the drawings forming a part thereof.

**SUMMARY OF THE INVENTION**

The present invention resides in a solar oxy-hydrogen vehicle comprising in combination an internal combustion engine including a fuel system delivering fuel and air for the combustion process wherein an electrolysis unit produces hydrogen and oxygen gases from an electrolyte and the electrolysis unit is connected through conduit means to the fuel system and feeds the gases produced into the engine for combustion with the fuel and air. An array of solar cells produces electrical current from light and the solar cells are connected with the electrolysis unit for sending current through the unit and producing the hydrogen and oxygen gases fed to the fuel system. The invention further resides in the electrolyte used wherein the electrolyte includes a hydride for absorbing and storing hydrogen generated by the electrolysis process and for absorbing heat produced by combustion when the engine is in operation to promote the disassociation of hydrogen stored in the hydride. The invention further resides in the electrolysis unit comprising the engine casing and the cooling system radiator wherein the radiator and engine casing are connected by electrically insulating fluid carrying conduits and the cooling fluid is the electrolyte. The engine casing forms one of the electrodes and produces one of the hydrogen and oxygen gases and the radiator forms the other of the electrodes and produces the other of the gases.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 illustrates the solar oxy-hydrogen fuel burning engine of the present invention embodied in an internal combustion engine of a vehicle,

FIG. 2 illustrates another embodiment of the invention in an internal combustion engine,

FIG. 3 illustrates a third embodiment of the invention showing a cross-sectional view of an electrolysis unit that may be used to produce hydrogen and oxygen gases,

FIG. 4 is a top plan view in cross-sectional along the line 4-4 of FIG. 3.

**DETAILED DESCRIPTION**

First by way of background and referring to FIG. 1, FIG. 1 illustrates an internal combustion engine shown generally by the numeral 10 that is mounted within an engine compartment of a vehicle below an overlying body panel 12. The engine 10 is conventional to the extent that it has a carburetor 14 for producing a mixture of fuel and air that is injected into the cylinders within the engine casing 16 where the mixture is burned to produce power. Exhaust gases from the combustion process are discharged through an exhaust system 18 including an exhaust pipe 20. The electrical system providing power for the engine and accessories includes a battery 22, a generator or alternator 24 driven from the engine, and a regulator and control unit 26 to operate and maintain the electrical charge in the battery. The engine casing 16 or block includes a jacket surrounding the cylinders and the jacket is connected through conduits 28,30 with a cooling means such as a radiator 32.

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All of the above components of the engine 10 are conventional parts of the power plants found in most trucks and automobiles as shown, for example, in U.S. Pat. No. 4,271,793 referenced above.

A radiant energy collecting system comprised by a plurality of solar cells 34 is mounted with the cells in an array on the body panel 12 to collect light and solar energy and generate direct current. The solar cells are enclosed in a sealed panel, such as a crystal sheet from which electrons are easily disassociated. The cells are interconnected to produce a voltage of approximately 2 volts between a negative output terminal 36 and a positive output terminal 38. The amperage between the two terminals when a load is connected is proportional to the number of panels. The solar cells are utilized to provide power for an electrolysis unit that generates hydrogen and oxygen gases.

Considering now the invention and still referring to FIG. 1, the electrolysis unit for producing hydrogen and oxygen gases comprises the engine casing 16 and the engine cooling system or radiator 32. An electrode, for example, the negative electrode of the electrolysis unit is formed by the engine casing 16 and is connected to the negative terminal 36 of the solar cells 34. The other electrode, the positive electrode of the unit, is formed by the radiator 32 which is of a noble metal to withstand corrosion and is correspondingly connected to the positive terminal 38 of the solar cells 34. The engine coolant itself is replaced by an electrolyte and electrically insulating fluid conduits such as rubber hoses 28,30 connect the radiator 32 to the jacket surrounding the cylinders in engine casing 16. The electrolyte provides an electrical current path between the positive and negative electrodes. During electrolysis, oxygen ions flow to the positive electrode and form an oxygen gas in the radiator 32, and the oxygen is bled through a valve 40 on the radiator 32 to the atmosphere. Hydrogen ions flow to the negative electrode and form hydrogen gas in the engine casing 16. The hydrogen gas is collected within the upper portion of the casing 16 which is connected by a valve 42 and a conduit 44 connecting the valve 42 to the carburetor 14 to provide hydrogen gas to the carburetor 14.

The electrolyte used with the present invention includes a hydride for absorbing and storing hydrogen generated by the current produced by the solar cells 34 when the engine is not in operation and consuming hydrogen gas fed to the carburetor 14. The hydride also absorbs heat produced by the combustion process when the engine is in operation to promote the disassociation of hydrogen stored in the hydride. Consequently, since the heat of combustion is absorbed by the hydride, a conventional cooling system is not necessary. Therefore, the water pump and conventional radiator associated with the cooling system can be eliminated and the radiator 32 is replaced with a reservoir means to hold a supply of electrolyte and to function as one of the electrodes. The hydride in the electrolyte also functions as a reserve source of hydrogen to supplement the hydrogen produced by electrolysis when the engine is in operation and consuming the hydrogen gas produced. The hydride is thermally activated, that is, hydrogen is more easily disassociated from the hydride when heat is added. Preferably, the hydride has an optimum hydrogen disassociation at a temperature of approximately 150° Fahrenheit to permit heat to be absorbed by the hydride to produce a sufficient quantity of hydrogen and still remain well below the boiling point of most

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electrolytes such as water. Consequently, since the heat is absorbed by the hydride the electrolyte will not boil-off during electrolysis and cooling of the electrolysis unit and accordingly the electrolyte is not required.

The hydride used in the electrolyte of the present invention is formed in the following manner. The hydride is produced from a reaction involving the dissolving of titanium in a sulfuric acid solution having a concentration in the range of 7 to 38%. A platinum electrode is used as the anode and a titanium electrode is used as the cathode with the titanium electrode providing the titanium for the solution. An electrical current is supplied at 12 volts to start the reaction and once the reaction is started it is self-sustaining and electrical current is no longer needed. The titanium dissolves in the sulfuric acid solution until saturation occurs, at which time the titanium-sulfate solution becomes black. An organic hydrocarbon compound, such as isopropyl alcohol having a 70% concentration, is added to the black solution in the proportion one part alcohol to five parts of the titanium-sulfate solution. A second voltage of approximately 2 volts is then applied across the anode and cathode to start electrolysis to produce hydrogen which is absorbed by the titanium-sulfate solution and causes a white precipitate to form and to turn the black titanium-sulfate solution clear. The titanium, carbon and hydrogen ions are now bonded together in the white precipitate which is the hydride. When the hydride is used in the electrolyte and is heated above 150° Fahrenheit, hydrogen is expelled and the solution begins to turn black again. The solar cells 34 generate a voltage of approximately 2 volts in magnitude and the electrical current produced is used to repeat the electrolysis process to continuously replenish the hydride with hydrogen. Therefore, the hydride may be regenerated without the necessity of a prolonged fuel stop.

FIG. 2 shows another embodiment of the present invention in an internal combustion engine wherein the electrolyte 46 is contained in the oil pan of the engine casing 16 and the casing is connected by an electrically insulating conduit 48 to a reservoir means 50. The engine casing 16 and reservoir means 50 form an electrolysis unit with the engine casing being the negative electrode and the reservoir means being the positive electrode. An array of solar cells 34 is mounted on a body panel 12 for producing electrical current from sunlight to power the electrolysis unit. The positive terminal of the solar cells 34 is connected via lead 38 to the reservoir means 50 which functions as an anode and the negative terminal of the solar cells is connected via lead 36 to the engine casing 16 which functions as the cathode. The electrolyte includes a hydride as described above for absorbing and storing hydrogen generated by the electrolysis process. The hydrogen produced by electrolysis and the hydrogen released from the hydride when the hydride is heated bubbles through the engine oil into the upper portion of the engine casing 16 where the hydrogen gas collects and is fed through a positive ventilation crankcase (PVC) valve 56 which is connected to the carburetor 14 by conduit 58. The oxygen gas generated during the electrolysis process is vented to the atmosphere through a vent 68 connected to the reservoir means 50.

Because the hydride absorbs the heat of combustion and the engine may be operated without a conventional cooling system it is possible to feed the fuel used in the fuel-air mixture through the jacket surrounding the cylinders in the engine casing 16 through an inlet 60.

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Hydrogen released from the hydride and produced by electrolysis is also bubbled through the engine fuel 62 flowing through the jacket where the fuel absorbs the hydrogen and becomes more volatile. The fuel 62 is fed through a valve 64 to the carburetor 14 via a conduit 66.

Turning now to FIGS. 3 and 4, an electrolysis unit also known as an electrolytic cell for producing hydrogen and oxygen gases for use with a fuel burning engine such as an internal combustion engine is shown generally by the numeral 70. An internal combustion engine is shown generally by the numeral 10 and is similar to the engine described in the above referenced patent. The electrolysis unit 70 is preferably cylindrical in shape having walls 80 which form one of the electrodes, that electrode being the cathode and producing hydrogen gas and the second electrode 72 being the anode and producing the oxygen gas. A source of electrical current such as solar cells 34 mounted on a body panel 12 provide current to the electrolysis unit 70. The anode 72 is connected to the positive terminal of the solar cells 34 by lead 38. The cathode 80 is connected to the negative terminal of the solar cells 34 by lead 36. The solar cells are connected in such a manner to produce a voltage of not more than 2 volts across the positive and negative terminals 36,38. Limiting the magnitude of the voltage used for electrolysis automatically limits the amount of current that can flow in the electrolysis unit 70 and accordingly any heat generated by the electrolysis process.

As is shown in FIGS. 3 and 4, the anode 72 extends into the electrolytic cell 70 through a lid 84 and the anode 72 is substantially coaxial with the cylinder wall 80. A bottom 82 and the lid 84 are fabricated from a non-conductive, non-corrosive material such as plastic to withstand corrosion and prevent current from flowing in a path other than that provided by the electrolyte.

A sleeve 78 is also fabricated from a non-conductive, non-corrosive material such as plastic and attaches to the lid 84 and surrounds the anode 72. The sleeve 78 extends into the electrolytic cell further than the anode 72, so that ion flow in the electrolyte 94 flows to the cathode 80 from the anode 72 through an aperture shown generally at 96 formed at the end of the sleeve 78 opposite the end attached to the lid 84. A relatively smaller ionic discharge area from the anode 72 to a much larger ionic receptive area such as the cathode 80 also minimizes heat generated in the electrolysis process and prevents electrolyte boiloff in the electrolytic cell without the need of external cooling.

Venting means 74 in the anode 72 allow the generated oxygen gases to escape to the atmosphere. A vent 76 in the lid 84 is connected by a conduit 96 to the carburetor 14 to deliver hydrogen gas formed and collected at the cathode 80. An inlet valve 86 is provided in the lid 84 for filling the electrolytic cell 70 with electrolyte 94.

A heat exchanger means 88 surrounds the electrolytic cell 70 and transfers heat to the electrolyte to promote the production of hydrogen. The heat exchanger is connected, for example, to the cooling system 32 and the cooling fluid is circulated through conduits 90,92 attached to the heat exchanger means 88 to transfer heat. Heat generated by the combustion process and expelled as exhaust gas may also be in communication with the heat exchanger means 88 to provide a source of heat to the electrolytic cell 70 to promote the production of hydrogen and oxygen gases.

A solar oxy-hydrogen fuel burning vehicle embodying the present invention has been described and shown

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in several preferred embodiments; however, numerous modifications and changes may be had without departing from the spirit of the invention. Therefore, the invention has been described by way of illustration rather than limitation.

I claim:

1. A solar oxy-hydrogen vehicle comprising in combination:

an internal combustion engine including a fuel system delivering fuel and air for the combustion process; an electrolyte;

an electrolysis unit for producing hydrogen and oxygen gases from said electrolyte and connected through conduit means with the fuel system for feeding the gases into the engine for combustion with the fuel and air;

an array of solar cells for the production of electrical current from light, the solar cells being connected with said electrolysis unit for sending current through the unit and producing the hydrogen and oxygen gases fed to the fuel system, and

said electrolyte including a hydride comprising titanium dissolved in a 7% to 38% concentrated sulphuric acid solution to form a titanium-sulfate solution which is reacted with an organic hydrocarbon compound whereby said hydride absorbs and stores hydrogen generated by the electrolysis process and absorbs heat produced by combustion when the engine is in operation to promote the disassociation of hydrogen stored in the hydride.

2. A solar oxy-hydrogen vehicle as defined in claim 1 wherein said titanium-sulfate solution is reacted with isopropyl alcohol having a 70% concentration, said alcohol being mixed with said titanium-sulfate solution in the proportion one part alcohol to five parts titanium-sulfate.

3. A solar oxy-hydrogen vehicle as defined in claim 1 wherein said engine includes an engine cooling system having a radiator, electrically insulating fluid carrying conduits and an engine casing jacket, and wherein said electrolysis unit further comprises the engine casing and the cooling system radiator, and the radiator and engine casing are connected by said electrically insulating fluid carrying conduits with the cooling fluid being the electrolyte, the engine casing forming one of the electrodes and producing one of the hydrogen and oxygen gases, the radiator forming the other of the electrodes and producing the other of the gases.

4. A solar oxy-hydrogen vehicle as defined in claim 3 wherein said radiator is constructed of a noble metal.

5. A solar oxy-hydrogen vehicle as defined in claim 1 wherein said electrolysis unit comprises:

container means having sides, a lid and a bottom for holding a quantity of electrolyte, the lid and bottom being made of a non-corrosive and electrically non-conductive material and the sides forming one of the electrodes for producing one of the hydrogen and oxygen gases;

second electrode means extending through the lid transversely into said container means for a first predetermined distance for producing the other of the gases;

means for applying an electrical potential across said first and said second electrode means;

shielding means surrounding said second electrode means and having one end attached to the container lid and the other end open and extending into said container for a second predetermined distance,

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said second predetermined distance being greater than said first predetermined distance, said shielding means further having a fixed, spatial relationship with said first and second electrode means to form a first channel between said shielding means and said first electrode and a second channel between said shielding means and said second electrode such that said second channel is smaller than said first channel whereby the ion flow in the electrolyte to said electrodes is limited so that heat produced by electrolysis is controlled to prevent electrolyte boil off, and

venting means associated with said first and said second electrode means for allowing the hydrogen and oxygen gases produced during electrolysis to be released from said electrolysis unit.

6. A solar oxy-hydrogen vehicle as defined in claim 5 further including a heat exchanging means associated with said electrolysis unit for transferring heat to said unit to promote the production of hydrogen and oxygen gases produced by electrolysis.

7. A solar oxy-hydrogen vehicle as defined in claim 5 wherein the means for applying an electrical potential across the first and second electrodes has an output voltage not more than two volts to limit the electrical current flowing in the electrolyte so that the heat produced by electrolysis is limited whereby cooling of the electrolysis unit is not required.

8. In a solar oxy-hydrogen vehicle, the combination comprising:

an internal combustion engine including a fuel system delivering fuel and air for combustion, a crankcase, a first conduit means connected to the fuel system and the engine crankcase for delivering gases in the crankcase to the fuel system;  
an electrolyte;

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electrically insulating conduit means for carrying a liquid;

reservoir means for holding a supply of said electrolyte and connected to the engine crankcase by said insulating conduit means with the electrolyte flowing between the engine crankcase and said reservoir means through said insulating conduit means; an electrolysis unit for producing hydrogen and oxygen gases from said electrolyte wherein said electrolysis means comprises said reservoir means and the engine crankcase, said reservoir means forming one of the electrodes and producing one of the hydrogen and oxygen gases, the engine crankcase forming the other of the electrodes and producing the other of the gases, and

an array of solar cells integrated into the body panels of the vehicle for the production of electrical current from light, the cells being connected to produce an electrical current at a potential of not more than two volts and also connected with said electrolysis means for energizing said electrolysis means and producing the hydrogen and oxygen gases.

9. In a solar oxy-hydrogen vehicle the combination as defined in claim 8 wherein said electrolyte includes a hydride for absorbing and storing hydrogen produced from the current of the solar cells passing through said electrolysis unit when the engine is not in operation and for capturing the heat of combustion when the engine is in operation to facilitate the release of hydrogen stored in the hydride.

10. In a solar oxy-hydrogen vehicle the combination as defined in claim 8 wherein said first conduit means connecting the engine crankcase and the fuel system is a positive crankcase ventilation valve.

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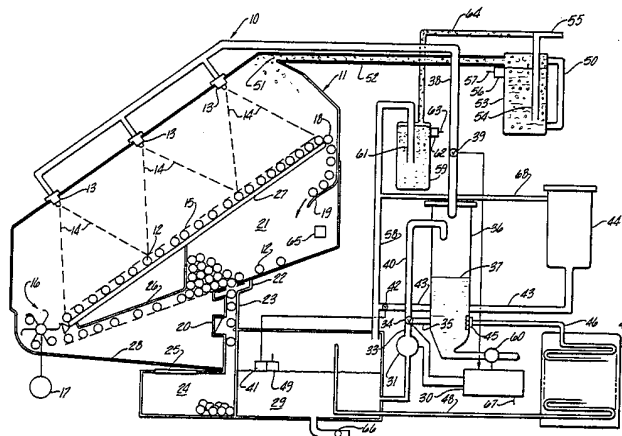
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**United States Patent** [19]**Houser**[11] **Patent Number:** **4,543,246**[45] **Date of Patent:** **Sep. 24, 1985**[54] **HYDROGEN GENERATOR**[76] **Inventor:** Clifford F. Houser, Flint, Mich.[21] **Appl. No.:** 657,508[22] **Filed:** Oct. 4, 1984[51] **Int. Cl.<sup>4</sup>** ..... C01B 13/00[52] **U.S. Cl.** ..... 423/648 R; 422/62;  
422/233; 423/659[58] **Field of Search** ..... 423/648 R, 659, 657;  
422/62, 109, 233, 235[56] **References Cited****U.S. PATENT DOCUMENTS**

2,045,429	6/1936	Willshaw et al.	423/233
3,313,598	4/1967	Gluckstein	423/657
3,392,003	7/1968	Partridge et al.	422/233
3,707,355	12/1972	Anderson	422/233
4,215,201	7/1980	Cerroni	422/233
4,288,410	9/1981	Weber et al.	422/233
4,325,355	4/1982	Houser	126/263

*Primary Examiner*—John Doll*Assistant Examiner*—Wayne A. Langel*Attorney, Agent, or Firm*—Fisher, Crampton, Groh & McGuire[57] **ABSTRACT**

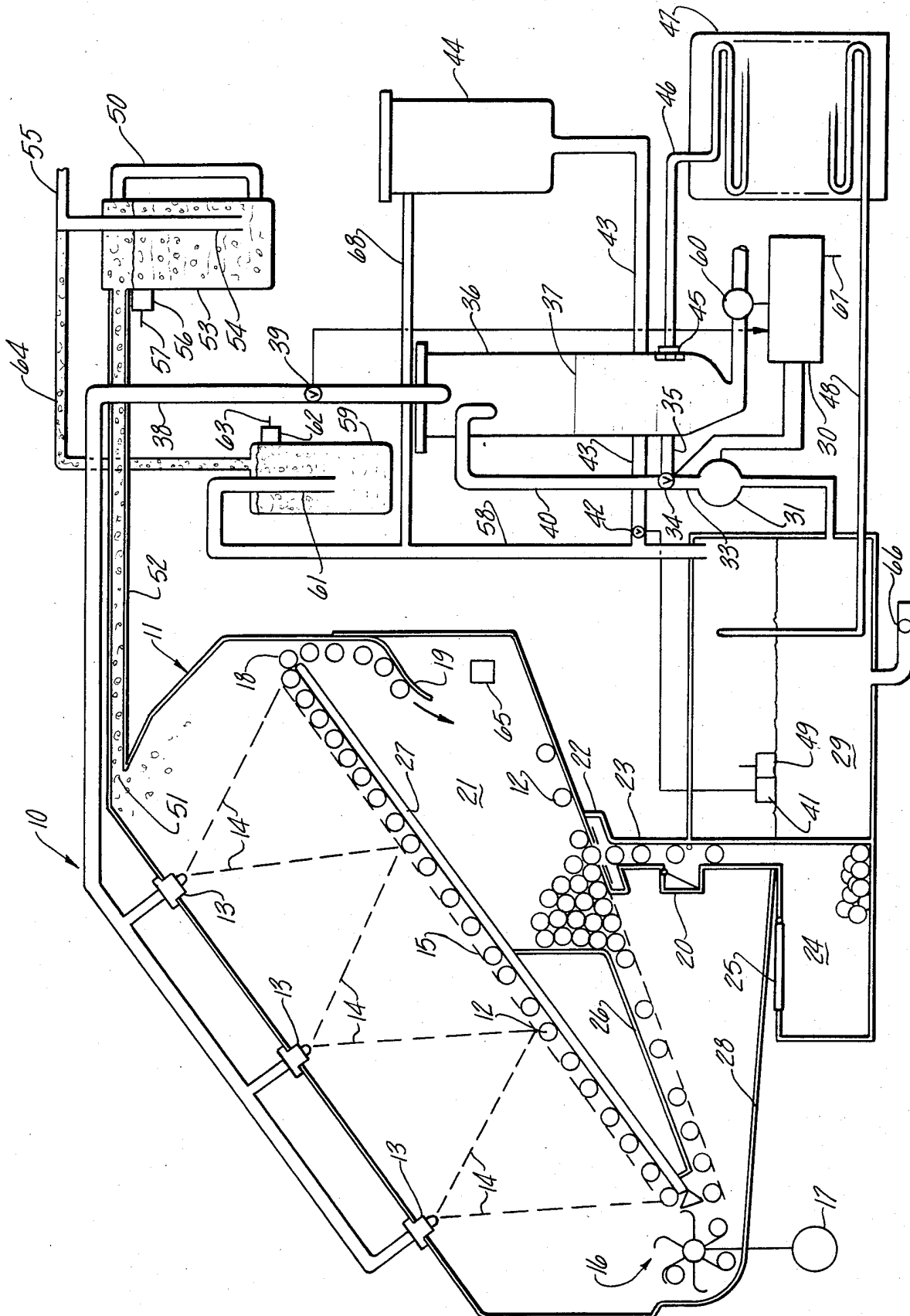
A gas generator in which the gas is produced by a reaction between a solid metal and a liquid reactant. The generator is operated to produce hydrogen intended as an energy source particularly for operating internal combustion engines. A solid reactant is reacted with a liquid reactant under conditions in which both reactants are moving and continuously maintained under operating conditions. The solid is in the form of metal balls which are conveyed through a reaction chamber on inclined perforate channels. The liquid reactant is sprayed over the moving balls. Waste solid reaction products are removed by the rolling action of the balls on the perforate channels and the washing action of the sprayed liquid reactant. In the production of hydrogen, aluminum metal balls are used and the liquid reactant is a solution of sodium hydroxide. Because the reaction is exothermic, excess heat is removed by cooling the liquid reactant.

**12 Claims, 1 Drawing Figure**

U.S. Patent

Sep. 24, 1985

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## HYDROGEN GENERATOR

### BACKGROUND OF THE INVENTION

#### (1) Field of the Invention

The subject invention relates to the gas generator field, and, more particularly, to the generation of hydrogen as an energy source in an environment where the total output of a given generator is dedicated to a single use such as supplying the energy for an internal combustion engine.

#### (2) Description of the Prior Art

Gas generators can take many forms generally involving a chemical reaction, a liquification-separation process or an electrolysis reaction. In the case of hydrogen production, most of the gas is manufactured from natural gas, which is mainly methane, CH<sub>4</sub>. Refinery gas which is produced during oil refining and is a mixture of methane, propane and butane, can also be used for hydrogen production. These gases are reacted with steam at elevated temperature in the presence of a catalyst to produce hydrogen and carbon monoxide. Carbon monoxide is usually reacted to carbon dioxide and then separated by an absorption process. This multi-step process involves complex high temperature equipment. The other main means of producing hydrogen is by electrolysis of water into its component oxygen and hydrogen gases; this involves large equipment and a source of cheap electricity. Other processes involve high temperature reactions such as partial combustion under carefully controlled conditions; all these processes result in gas mixtures from which the hydrogen must be separated.

On a smaller scale, U.S. Pat. No. 3,975,913 teaches a method of producing hydrogen by the reaction of a liquid metal with a gas, such as liquid aluminum and steam at a temperature of 1400° F.

In my own U.S. Pat. No. 4,325,355, I have set forth a heating system utilizing an exothermic reaction of a solid metal, preferably aluminum, and a solution, preferably containing the reactant sodium hydroxide. The exothermic heat releases is indirectly transferred for conventional space heating. A bi-product of this heating system is the production of hydrogen.

It is a object of this invention to utilize a simple low temperature, flameless chemical reaction such as taught in U.S. Pat. No. 4,325,355 to produce hydrogen gas.

It is also an object of this invention to provide a method and apparatus for continuously producing hydrogen to be used as the fuel source of an internal combustion engine, thus requiring a compact, portable gas generator.

Another object is the production of hydrogen gas from readily available reactants.

### BRIEF SUMMARY OF THE INVENTION

The instant invention is directed to a method and apparatus for producing a gas continuously by the reaction of a solid material with a liquid in a low temperature, low pressure environment with compact and portable means.

The generator utilizes a supply of balls made from the solid reactant material. These balls are circulated through a reaction chamber by rolling them up inclined perforate channels. These channels can take the form of screen mesh tubing. The liquid reactant material is sprayed from a plurality of spray nozzles downwardly on the ascending balls. The waste solid reaction prod-

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ucts are removed from the reacting balls by the rolling action of the balls against the perforate channels and the washing action of the sprayed liquid reactant which passes through and down the perforate channels by gravity and is led out the reaction chamber. The liquid reactant is led back to a sump from whence it pumped through a sediment filter to remove the solid waste reaction product and then back to the spray nozzles in the reaction chamber. The concentration of the liquid reactant is controlled from a sensor in the liquid sump which controls the addition of concentrated make up solution. The temperature of the liquid reactant is also maintained from a sensor in the liquid sump or a thermostatic valve in the sediment filter which allows the liquid to flow through an indirect heat exchanger. The balls exit from the reaction chamber by gravity into a supply receiver. The balls are fed by gravity to the entrance end of the reaction chamber where pawl and ratchet wheel means introduces the balls, one at a time, to the channels. When the balls have eroded to a minimum size by the chemical reaction, they are ejected from their flow path by falling through a gauge slot into a spent ball receiver. The generated gas is delivered from the reaction chamber by its own back pressure built up in a flash-back preventor/gas washer unit in the gas outlet line.

The method of producing the gas from a reaction of a solid reactant and a liquid reactant involves supplying the solid reactant in the form of balls to a continuous flow path. The balls are sprayed with liquid reactant to release the gas. The liquid reactant also serves to carry away waste solid reaction products. The liquid reactant is collected after being sprayed and is circulated in a closed flow path in which heat exchange takes place to control temperature and filtration takes place to remove the waste solid reaction products. Concentrated liquid reactant is added to the liquid flow path to control concentration.

In the preferred form of the invention, hydrogen is produced by the exothermic reaction of aluminum and a solution of sodium hydroxide. Heat exchange with reactant liquid must remove excess heat to control temperature.

### THE DRAWING

The single FIGURE drawing is a diagrammatic view showing a gas generator embracing the preferred embodiment of the invention.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

Referring to the drawing, the gas generator shown generally at 10 includes reaction chamber 11 in which a chemical reaction takes place between a solid reactant in the form of balls 12 and a liquid reactant sprayed from nozzles 13 in a spray pattern 14 to cover balls 12 as they travel upwardly through chamber 11 in a plurality of side by side inclined perforate channels 15 which may take the form of screen mesh tubes. The balls 12 are fed into perforate channels one at a time by pawl and ratchet wheel ball feeder 16 driven by reduction motor 17. The balls exit from the reaction chamber 11 through opening 18 and travel by gravity along ball return guide 19 into and through ball receiver chamber 21. New balls are loaded into receiver chamber 21 as needed. As the balls are circulated through the system they decrease in



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size due to the erosion accompanying the chemical reaction. When the balls have been reduced in diameter to a certain point they become less effective than desired. In the preferred embodiment where hydrogen gas is being generated, the balls 12 are made from aluminum metal and they are supplied to chamber 21 with a one inch diameter. When the balls have been eroded to a  $\frac{3}{4}$ " diameter they are not effective enough, having had their surface area reduced by over 40%, and they are difficult to handle by ball feeder 16. In order to remove undersized balls automatically a ball slot gauge 22 is located in the path of the balls travelling through the chamber 21. The gauge 22 can be set at any desired size to allow the undersized balls to pass therethrough. The undersized balls drop by gravity through slot 22, chute 23 and into spent ball receiver 24. The undersized balls can be retrieved from receiver 24 by opening removable cover 25. In order for to preserve the gas atmosphere of the gas being produced in the chamber 11 throughout the system, including ball receiver chamber 21, flapper valve 20 located in chute 23 is closed when balls are being removed from spent ball receiver 24. Balls 15 travel in their continuous path from receiver chamber 21 to ball feeder 16 by gravity through passage 26.

The liquid reactant as well as the solid reactant in the form of balls 12 is also circulated in a continuous path. In the preferred embodiment where hydrogen is being generated and the solid reactant balls are aluminum, the preferred liquid reactant is a solution of sodium hydroxide, and the waste product is sodium aluminate. As mentioned above, the liquid reactant is sprayed downwardly from nozzles 13 in a spray pattern 14 to cover the balls ascending through the chamber 11. The waste solid reaction products are removed from balls 12 by the rolling action of the balls against the perforate channel 15. In the preferred embodiment, where the new aluminum balls have a 1 inch diameter, the perforate channel can take the form of a screen mesh tube of  $1\frac{1}{8}$ " diameter which will provide a good cleaning action against the balls being rolled and pushed against each other through the inclined screen tube. The washing action of the sprayed liquid reactant will remove the waste solid product, which is in the form of a sediment, from balls 12 and the surface of perforate tube or channels 15. The liquid reactant will travel by gravity from inclined surface 27, down return drain ramp 28 into sump 29 which is a reservoir of liquid reactant. Drain ramp 28 is below ball feeder 16 so that the balls 12 will not be immersed in the liquid reactant in their return travel, exiting from reaction chamber 11, through ball opening 18, down ball return guide 19, through ball receiver chamber 21, passage 26 to the ball feeder 16. The liquid reactant or solution is pumped by pump 31 from sump 29 through passage 32, pump 31, passage 33, two way valve 34 and passage 35 into sediment filter 36. The sediment in the solution is removed by filter elements 37. The solution is pumped from filter 36 through pipe 38 containing flow responsive element 39, to spray nozzles 13. When the gas flow through pipe 38 drops, as sensed by flow responsive element 39, it indicates that sediment filter elements need to be cleaned. Master controller 30 automatically actuates two way valve 34 to direct the flow of reactant solution through passage 40 to the top of filter 36. Master controller 30 also opens drain valve 60 allowing solution to flow downward through filter elements 37 flushing the sediment out and through valve 60 to a receiver, not shown. The system will continue to operate during this back flush. Sedi-

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ment can also be manually drawn off from the bottom of sump 29 by opening drain valve 66. The concentration of the liquid reactant solution is maintained by a measurement of concentration in sump 29 by control 41. Concentration control 41 can utilize a liquid level sensing element or a specific gravity measuring device which acts to open or close valve 42 in line 43 to add concentrated solution from make-up tank 44 to sump 29. Optionally, concentration control 41 could use a specific gravity sensing element to control the flow of concentrated solution from make-up tank 44, and also a liquid level sensing element to control the addition of water to sump 29 from a water inlet, not shown.

For optimum operating conditions, the temperature of the liquid reactant is controlled. In the preferred embodiment, producing hydrogen by the reaction of aluminum with sodium hydroxide, the reaction is exothermic so that heat must be continually removed. For optimum reaction the reactant solution should be maintained between 140°-160° F. this temperature control can be accomplished by passing a portion of the solution being circulated by pump 31 from the sediment filter 36, through thermostat valve 45, line 46, air cooled radiator 47, return line 48 to sump 29. Simple thermostat valve 45 serves to measure the solution temperature and serves as an on-off valve to pass the liquid through the radiator 47 only when it needs cooling. The air cooled radiator 47 is a simple indirect heat exchanger, and, in the preferred application of generating hydrogen gas for operating an automotive internal combustion engine, a radiator is ideal. A temperature sensor 49 can be used alternatively to actuate cooling valve 45 or it can serve to actuate a high temperature warning.

The gas generated by the reaction collects in reaction chamber 11 which acts as a surge tank, when hydrogen is being generated, it naturally rises to the top of the chamber, being 16 times lighter than air. The gas outlet 51 from reaction chamber 11 is located at the peak of the chamber leading into delivery tube 52 through which the gas passes to liquid filled vessel 53 which serves as a back flash preventer in sealing the generated gas from atmosphere, and it serves as a gas washer. The gas enters the top space of vessel 53 and bubbles through the liquid contained in the vessel to the bottom of outlet tube 54 through which it passes to use outlet 55. Level controller 56 serves to maintain a constant liquid level in vessel 53 by admitting make-up liquid from line 57. The liquid used in vessel 53 is water based, its composition depending upon the gas being generated. In most cases where hydrogen is being generated the liquid can be plain water. The immersed length of outlet tube 54 establishes the back pressure in the entire system. An immersed length of 5" maintained by level controller 56 in the preferred hydrogen generator embodiment. The back pressure would be 5" w.c. Sight glass 50 is provided on the side of vessel 53 to permit visual observation of liquid level. When the generator is started, it is necessary to purge the system of air. This is facilitated by the use of vent tube 58 which extends into sump vessel 29 which is the lowest point in the system. Vent tube 58 extends from sump chamber 29 into liquid filled vessel 59, which, like vessel 53, serves as a back flash preventer and a gas washer. The gas exits from the bottom of the drop tube portion 61 of vent tube 58 and bubbles through the liquid to the top of the vessel. Level controller 62 serves to maintain a constant liquid level in vessel 59 by admitting make-up liquid from line 63. The immersed length of drop tube 61 is less than the

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immersed length of tube 54 in vessel 53 allowing the back pressure established by vessel 53 to force the air out through vent tube 58, vessel 59 and tube 64 to gas use outlet 55. Vent tube 68 is used to supply gas to the top of make-up tank 44 as concentrated solution is drawn off to add to sump 29. Serving a similiar function, is vacuum breaker 65 located in ball receiving chamber 21 which is used to relieve vacuum by the cooling effect of balls 12 cooling as they pass through chamber 21 and back to ball feeder 16. The rate of gas production can be controlled by the rate of reactant solution flow delivered by pump 31 in response to a demand signal delivered by line 67 to master controller 30.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A gas generator for continuously producing a gas by the reaction of a solid and a liquid reactant. comprising, in combination:

a supply of balls made from a solid reactant material; a reaction chamber;

means for conveying said balls from said supply through said reaction chamber and back to said supply;

spray means within said reaction chamber for directing a spray of liquid reactant on to said balls passing therethrough;

means for delivering said liquid reactant from a sump, through said spray means and into contact with said balls and back to said sump; and

means for delivering gas generated by the contact of said liquid reactant and said solid reactant balls from said reaction chamber.

2. The gas generator of claim 1 wherein said means for conveying the balls through the reaction chamber includes an inclined surface within said chamber; and further including:

means for introducing the balls one at a time to said inclined surface in a manner such that the balls are conveyed up said inclined surface by pushing against one another.

3. The gas generator of claim 2 wherein said inclined surface comprises a plurality of channels in which the balls are conveyed in single rows and the conveying

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means includes a pawl and ratchet wheel means to introduce the balls one at a time to said chamber.

4. The gas generator of claim 3 wherein said channels are made from perforate material so as to facilitate the flow of liquid reactant away from said balls for return to said pump along with solid products of reaction which can be removed from said balls by rolling contact with said perforate channels.

5. The gas generator of claim 4 wherein said channels are made in the form of screen mesh tubing.

6. The gas generator of claim 1 further comprising: means for removing said balls from said conveying means when the balls become undersized due to the continuing reaction.

7. The gas generator of claim 1 comprising: control means for maintaining the concentration of said liquid reactant.

8. The gas generator of claim 1 further comprising: control means for maintaining the temperature of said liquid reactant.

9. The gas generator of claim 1 wherein the the solid reactant balls are made of aluminum.

10. The method of producing a gas by the exothermic reaction of a solid and liquid reactant wherein the solid reactant is in the form of balls, comprising the following steps, in combination:

causing the balls to move in a continuous flow path; spraying the balls with said liquid reactant over a portion of said flow path;

removing the gas formed by the reaction of said liquid reactant with the solid reactant balls;

controlling the temperature by removing the excess heat generated from the exothermic reaction by heat exchange to said liquid reactant;

removing solid products of reaction formed by said reaction, at least in part, by filtration of said liquid reactant.

11. The method of producing gas according to claim 10 wherein the solid reactant balls are aluminum, the liquid reactant includes sodium hydroxide and the solid products of reaction include sodium aluminate.

12. The method of producing a gas according to claim 10 wherein the rate of gas production is controlled by the rate at which the liquid reactant is sprayed on said balls of solid reactant.

\* \* \* \* \*

**United States Patent** [19]**Matsubara et al.**[11] **Patent Number:** **4,570,446**[45] **Date of Patent:** **Feb. 18, 1986****[54] FUEL TANK FOR HYDROGEN VEHICLE  
AND FUEL SUPPLYING SYSTEM**[75] **Inventors:** Yutaka Matsubara, Kodaira; Hisao Konno, Chofu; Takashi Sasai, Gunma, all of Japan[73] **Assignees:** Mitsui & Co., Ltd.; Japan Metals and Chemicals Co., Ltd., both of Tokyo, Japan[21] **Appl. No.:** 669,061[22] **Filed:** Nov. 7, 1984**[30] Foreign Application Priority Data**

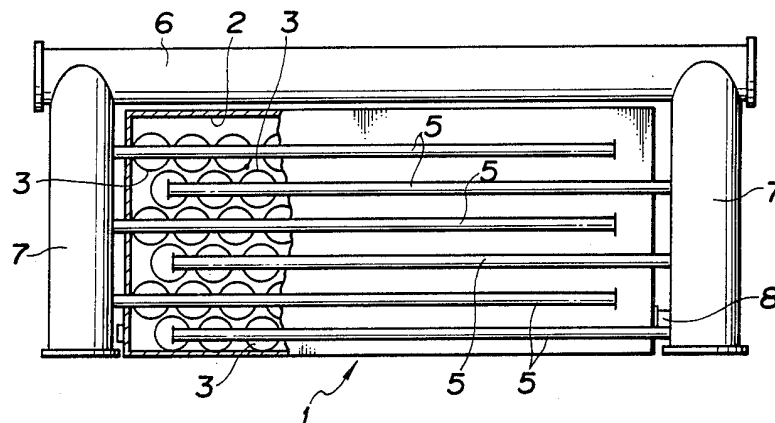
May 22, 1984 [JP] Japan ..... 59-102998

[51] **Int. Cl.<sup>4</sup>** ..... **F17C 11/00**[52] **U.S. Cl.** ..... **62/48; 123/1 A;**  
123/DIG. 12; 423/248[58] **Field of Search** ..... **62/48; 123/1 A, DIG. 12;**  
423/248**[56] References Cited****U.S. PATENT DOCUMENTS**

3,732,690	5/1973	Meijer	123/1 A
4,165,569	8/1979	Mackay	62/48
4,214,699	7/1980	Buchner et al.	62/48
4,393,924	7/1983	Asami et al.	62/48
4,402,187	9/1983	Golben et al.	62/48

*Primary Examiner*—Ronald C. Capossela*Attorney, Agent, or Firm*—Parkhurst & Oliff**ABSTRACT**

A fuel tank for a hydrogen vehicle in which a plurality of fuel cylinders are disposed and contained in a casing of the fuel tank for containing hydrogen storage alloy, the fuel cylinders are connected to a header mounted integrally with the casing for containing the fuel cylinders, a conduit for supplying engine exhaust gas is connected to the casing for externally heating the fuel cylinders in the casing. Further, a fuel supplying system which comprises supplying hydrogen gas from a fuel supply conduit connected to a header mounted integrally with the fuel tank, supplying the hydrogen gas from the openings of a plurality of fuel cylinders into the inner cylinder sections of the fuel cylinders to allow the hydrogen gas to be absorbed to hydrogen storage alloy of the respective fuel cylinders, supplying air or water from an engine exhaust gas passage of a fuel tank casing into the casing in case of supplying the hydrogen while cooling the fuel cylinders from the exterior, closing the fuel supply conduit of the header after filling the hydrogen gas of a predetermined amount, and then supplying the exhaust gas through the engine exhaust gas passage to externally heat the fuel cylinders in case of desorbing the hydrogen gas in the fuel tank. Thus, the fuel tank can desorb or absorb hydrogen under a relatively low pressure and can store the hydrogen in the amount corresponding to the running distance of a gasoline vehicle in a compact structure.

**11 Claims, 4 Drawing Figures**

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FIG. 1

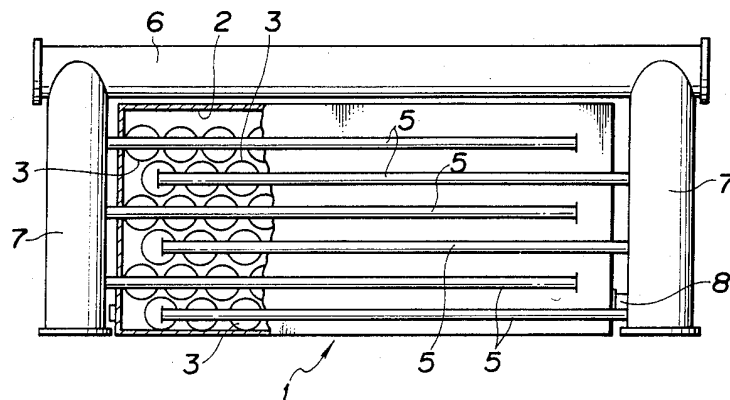
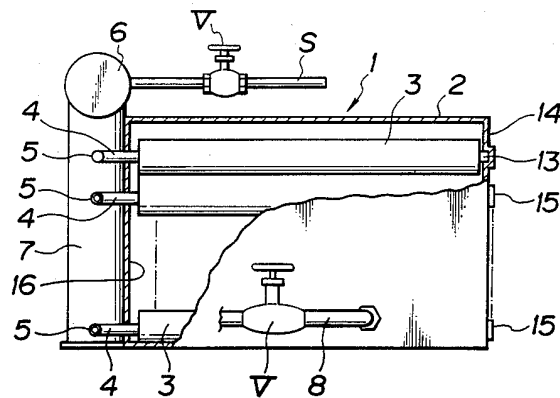
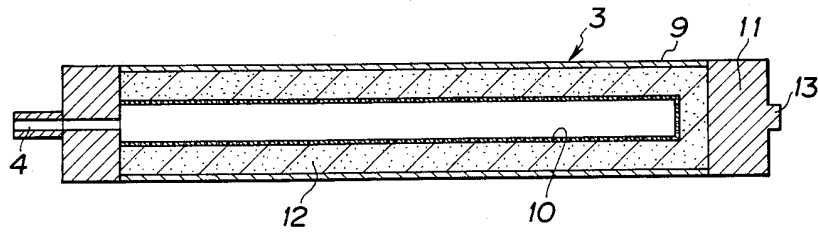


FIG. 2

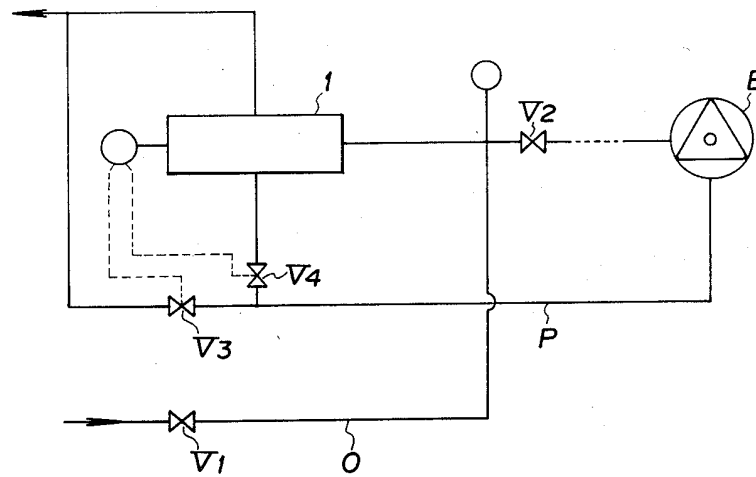


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F I G . 3



F I G . 4



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## FUEL TANK FOR HYDROGEN VEHICLE AND FUEL SUPPLYING SYSTEM

### BACKGROUND OF THE INVENTION

This invention relates to a fuel tank for a hydrogen vehicle and a fuel supplying system.

Recently, a vehicle which uses as fuel gasoline constitutes a social problem due to public pollution by exhaust gas discharged from the vehicle, and a vehicle which employs hydrogen gas as fuel and does not cause a public pollution is being developed at present.

However, since combustion reaction of hydrogen in the vehicle which employs hydrogen as fuel is remarkably faster than the combustion velocity of gasoline in the conventional vehicle which employs the gasoline as fuel, it is difficult to convert the combustion energy of the hydrogen into mechanical energy, and it is necessary to develop a new engine adapted therefor.

On the other hand, the hydrogen vehicle cannot employ a simple fuel tank like a conventional gasoline tank because the hydrogen is in gas phase at ambient temperatures. To this end, a variety of hydrogen storage alloys have been developed to absorb and desorb the hydrogen. It is desired to urgently develop a fuel tank capable of absorbing a considerable amount of hydrogen safely in the same manner as the conventional gasoline vehicle with the hydrogen absorption alloys, but such fuel tank which can sufficiently satisfy the safety factor has not yet been developed.

### SUMMARY OF THE INVENTION

It is an object of this invention to provide a fuel tank for a hydrogen vehicle which can desorb or absorb hydrogen under a relatively low pressure and can store the hydrogen in the amount corresponding to the running distance of a gasoline vehicle in a compact structure.

According to one aspect of the present invention, there is provided a fuel tank for a hydrogen vehicle in which a plurality of fuel cylinders are disposed and contained in a casing of the fuel tank for containing hydrogen storage alloy, the fuel cylinders are connected to a header mounted integrally with the casing for containing the fuel cylinders, a conduit for supplying engine exhaust gas is connected to the casing for externally heating the fuel cylinders in the casing.

According to another aspect of the present invention, there is provided a fuel supplying system which comprises supplying hydrogen gas from a fuel supply conduit connected to a header mounted integrally with the fuel tank, supplying the hydrogen gas from the openings of a plurality of fuel cylinders into the interiors of the inner cylinder sections of the fuel cylinders to allow the hydrogen gas to be absorbed to hydrogen storage alloy filled between the outer cylinder section and the inner cylinder sections of the respective fuel cylinders through ultrafine pores formed at the inner cylinder sections, supplying air or water from an engine exhausts gas passage of a fuel tank casing into the casing in case of supplying the hydrogen while cooling the fuel cylinders from the exterior, closing the fuel supply conduit of the header after filling the hydrogen gas of a predetermined amount, and then supplying the exhaust gas through the engine exhaust gas passage to externally heat the fuel cylinders in case of desorbing the hydrogen gas in the fuel tank.

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The fuel cylinder of the fuel tank of the present invention is composed of an inner cylinder section formed with a number of ultrafine pores and an outer cylinder section in a double structure, and hydrogen storage alloy for absorbing or desorbing the hydrogen gas is filled between the inner cylinder section and the outer cylinder section. The hydrogen storage alloy used in the fuel tank of the invention desirably has 10 kg/cm<sup>2</sup> or lower, and preferably 5 to 3 kg/cm<sup>2</sup> of hydrogen absorbing and desorbing pressures at the vicinity of ambient temperatures. To this end, the hydrogen storage alloy may employ lanthanum pentanickel LaNi<sub>5</sub> alloy, mischmetal-nickel alloys or mischmetal alloys containing high content of lanthanum, Ti—Zn—Mn—Cr—Cu alloys, or Mg based alloys.

The heat transfer property of the hydrogen storage alloys is preferably improved. For that purpose, 2 to 5 wt. % of acicular aluminum is preferably mixed with the hydrogen storage alloys.

The inner and outer cylinder sections of the fuel cylinder is preferably formed of stainless steel by considering the heat resistance and durability of the cylinder sections, and the inner cylinder section may also be formed of metal gauze of stainless steel.

One end of the outer cylinder section of the fuel cylinder is closed, and an opening is formed at the other end to communicate with the interior of the inner cylinder section. A plurality of the fuel cylinders are disposed and contained in the casing of the fuel tank, and the openings of a plurality of fuel cylinders are bundled to communicate with a header mounted integrally in the casing.

On the other hand, an exhaust gas passage which guides the exhaust gas of a vehicle engine is formed in the casing of the fuel tank to externally heat the plurality of fuel cylinders in the casing.

When filling the hydrogen gas in the fuel tank of the invention, the fuel cylinders are evacuated through the fuel supply conduit mounted at the header before supplying the hydrogen gas into the fuel cylinders to sufficiently evacuate the air in the plurality of fuel cylinders and the heater.

Then, the hydrogen gas is supplied from the fuel supply conduit of the heater. The hydrogen gas is supplied from the fuel supply conduit of the header through the header into the openings of the plurality of fuel cylinders into the interiors of the inner cylinder sections to allow the hydrogen gas to be absorbed by the hydrogen storage alloy through the ultrafine pores formed at the inner cylinder section.

Since the reaction in case the hydrogen gas is absorbed or occluded into the hydrogen storage alloy is exothermic, air or water is supplied from the engine exhaust gas passage of the casing of the fuel tank into the casing in case of supplying the hydrogen gas into the fuel tank to supply the hydrogen gas while externally cooling the plurality of fuel cylinders, and the fuel supply conduit of the header is then closed after a predetermined amount of hydrogen gas is filled in the fuel tank.

Since the reaction when the hydrogen gas of the fuel tank is then desorbed in endothermic contrary to the absorption of the hydrogen by the hydrogen storage alloy described above, the exhaust gas is supplied through the engine exhaust gas passage mounted in the casing of the fuel tank to externally heat the plurality of fuel cylinders. In this case, the desorbing pressure of the hydrogen gas from the hydrogen storage alloy is 10 kg/cm<sup>2</sup> or lower and preferably 5 to 3 kg/cm<sup>2</sup> similar to

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the absorption of the hydrogen by the hydrogen storage alloy as described above.

The reason why the absorbing and desorbing pressures of the hydrogen is 10 kg/cm<sup>2</sup> or lower in the present invention is because, in case of 10 kg/cm<sup>2</sup> or higher, it is restricted by the application of the stipulation of Japanese High Pressure Restriction Law, the materials and pipings of the casing, fuel cylinders used in the fuel tank should be those which can endure against high pressure, so that the materials should be restricted complicatedly, with the result that the materials become heavy and expensive as well as dangerous in actual vehicles.

Since the plurality of fuel cylinders of the fuel tank of the invention is externally heated by the exhaust gas of the hydrogen gas engine as a heat source of the case of desorbing the hydrogen gas from the hydrogen storage alloy, a special separate heat source is not necessary to desorb the hydrogen gas from the hydrogen storage alloy, thereby constructing the fuel tank in a compact structure. Further, the present invention can be applied to the conventional hydrogen gas engine, and the present invention is particularly effective for the hydrogen-water engine in which atomized water is mixed with the hydrogen gas.

More particularly, since the exhaust gas of the engine in case of hydrogen solely becomes considerably high temperature (approx. 1,000° C.), the fuel cylinders cannot be heated as they are, but the exhaust gas should be supplied to the fuel tank while suitably cooling the exhaust gas. However, the exhaust gas of the hydrogen-water engine is lower than the former at the temperature, and the exhaust gas can be supplied to the fuel tank as it is without forcibly cooling the exhaust gas, thereby reducing the weight and size of the fuel tank.

In addition, since the header is mounted separately from the fuel tank in the conventional hydrogen fuel tank, the header vibrates during the travelling of the vehicle, and the hydrogen gas might be accordingly leaked. However, since the header is mounted integrally with the fuel tank in the present invention, the header might not vibrate, and the entire assembly can be constructed compactly.

According to the present invention as described above, the fuel cylinders which fill hydrogen gas in the hydrogen storage alloy under the absorbing and desorbing pressures of 10 kg/cm<sup>2</sup> or lower are disposed in the casing of the fuel tank, the hydrogen gas can be respectively filled in or exhausted from the fuel tank under the absorbing and desorbing pressures of 10 kg/cm<sup>2</sup> by externally cooling or heating the plurality of fuel cylinders. Therefore, the hydrogen gas can be handled substantially in the same simple manner as the conventional gasoline engine. Since the fuel tank of the invention can be further reduced in weight and size, the fuel tank can be excellently used in the actual vehicle.

These and other objects and features of the present invention will be obvious from the following detailed description of the invention will be best understood when read in connection with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a fragmentarily front view of an embodiment of a fuel tank for a hydrogen vehicle constructed according to the present invention;

FIG. 2 is a fragmentarily side view of the fuel tank;

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FIG. 3 is a sectional view of one example of the fuel cylinder used in the fuel tank of the invention; and

FIG. 4 is a flowchart showing an example of absorbing and desorbing the hydrogen gas.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the present invention will now be described in detail with reference to the accompanying drawings.

FIGS. 1 and 2 show an embodiment of a fuel tank according to the present invention. In the embodiment shown in FIGS. 1 and 2, in a fuel tank 1 is disposed and contained a plurality of cylindrical fuel cylinders 3 in a casing 2. The fuel cylinders 3 are arranged so that a plurality of openings 4 disposed in the same plane are respectively connected to conduits 5 disposed horizontally.

On the other hand, a header 6 formed in a gate shape is mounted integrally with the casing 2 in front of the casing 2, and the conduits 5 connected to the openings 4 of the plurality of fuel cylinders 3 disposed in the same plane are alternately connected to the left and right post portions 7 of the header 6 for each plane.

An exhaust gas conduit 8 for supplying engine exhaust gas is mounted on one side wall of the casing 2, and an exit (not shown) for the exhaust gas is formed at the side wall opposite to the side wall of the casing 2. In FIG. 2, reference character S designates a hydrogen gas conduit, and V designates a valve.

FIG. 3 is an enlarged sectional view of one example of the fuel cylinder used in the fuel tank of the invention. The fuel cylinder 3 is composed of an outer cylinder section 9 and an inner cylinder section 10. A cover 11 is mounted sealingly on one end of the outer cylinder section 9, the opening 4 is formed at the other end of the outer cylinder section 9 to communicate with the interior of the inner cylinder section 10. Hydrogen storage alloy 12 (containing 2 to 5 wt. % of acicular aluminum) is filled between the outer cylinder section 9 and the inner cylinder section 10. A number of ultrafine pores are formed at the inner cylinder section 10 to be able to absorb and desorb the hydrogen gas.

The plurality of fuel cylinders 3 in the casing 2 are necessarily disposed in a small gap therebetween, and a connector 13 is mounted on the outside surface of the cover 11 closed on one end of each fuel cylinder 3 therefor. The connector 13 is engaged with a recess 15 formed on the wall 15 of the back surface of the casing 2, and the other end of the fuel cylinder 3 is constructed to clamp the plurality of fuel cylinders 3 via the wall 16 of the front side of the casing 2.

In operation for filling the hydrogen gas in the fuel tank 1, the hydrogen gas is supplied from the hydrogen gas conduit 5 while supplying air or water from the exhaust gas conduit 8. The hydrogen gas is supplied through the header 6 and the conduit 5 into the interiors of the inner cylinder sections 10 of the plurality of fuel cylinders 3 in the casing 2, and further absorbed into the hydrogen storage alloy 12 through the ultrafine pores of the inner cylinder sections 10 of the fuel cylinders 3.

After the hydrogen gas is absorbed to the fuel tank while cooling the fuel cylinders 3 in the fuel tank as described above, the valve V of the hydrogen gas conduit S is closed, and the air or water supply from the exhaust gas conduit 8 is stopped.

Then, in operation for desorbing the hydrogen gas from the fuel tank 1, the exhaust gas of the engine is

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supplied from the exhaust gas conduit 8 to externally heat the plurality of fuel cylinders 3, and valve V of the hydrogen gas conduit S is opened. Then, the hydrogen gas desorbed from the hydrogen storage alloy 12 by the external heat is desorbed from the alloy through the ultrafine pores of the inner cylinder sections 10 of the fuel cylinders 3 into the interiors of the inner cylinder sections 10 in the fuel tank, and exhausted through the openings 4, and the header 6 from the hydrogen gas conduit S. Particularly in the present invention, since the acicular aluminum is mixed with the hydrogen storage alloy 12 in the fuel cylinders 3, the heat transfer property of the hydrogen storage alloy 12 can be largely improved.

Since the hydrogen storage alloy used in the present invention can absorb or desorb the hydrogen gas under the pressure of 10 kg/cm<sup>2</sup> and preferably 5 to 3 kg/cm<sup>2</sup>, the fuel tank can be handled under the low pressure and the materials for the fuel tank and piping can employ not particularly restricted one. Therefore, the fuel tank of the invention is inexpensive and can be reduced in weight and size in a compact structure.

FIG. 4 shows an example of a flowchart for absorbing and desorbing hydrogen gas in the fuel tank of the invention. The hydrogen gas is supplied from the conduit O by opening the valve V<sub>1</sub> and closing the valve V<sub>2</sub>, and supplied through a pressure gauge PL to the fuel tank 1.

After the hydrogen gas is filled completely, the hydrogen gas is supplied to the engine E to burn the hydrogen gas in the engine by closing the valve V<sub>1</sub> and opening the valve V<sub>2</sub>.

On the other hand, the exhaust gas of the engine E is exhausted via the exhaust gas pipe P, supplied to the fuel tank 1 by closing the valve V<sub>1</sub> and opening the valve V<sub>2</sub>, thereby externally heating the plurality of fuel cylinders to desorb the hydrogen gas from the fuel tank. In this case, a temperature controller TIC mounted at the fuel tank 1 detects the exhaust gas temperature. When the exhaust gas temperature is suitable, the valve V<sub>3</sub> is closed, the valve V<sub>4</sub> is opened while when the exhaust gas temperature is raised, the temperature controller actuates to open the valve V<sub>3</sub> and to closed the valve V<sub>4</sub>, thereby externally exhausting the exhaust gas. Therefore, in the present invention, when the exhaust gas temperature is high, the exhaust gas is not supplied into the fuel tank 1. However, when the hydrogen-water engine is used, the exhaust gas temperature is relatively low, and it is particularly advantageous.

As an example, the fuel tank of the present invention can fill hydrogen gas of nine hydrogen bombs in sixty-five fuel cylinders, and can obtain performance capable of the conventional gasoline engine which can travel in the distance of approx. 350 km.

What is claimed is:

1. A fuel tank in a fuel supplying device for a hydrogen vehicle having a hydrogen-water engine comprising:

- a casing for the fuel tank,
- a header mounted integrally with said fuel tank,
- a plurality of fuel cylinders disposed in said casing and connected to said header for respectively containing hydrogen storage alloy selected from the group consisting of LaNi<sub>5</sub>, mischmetal alloys, Ti-Zr-Mn-Cr-Cu alloys and Mg light alloys,
- a hydrogen gas supply conduit connected to said header, and
- an exhaust gas supply conduit connected to said casing for supplying the exhaust gas to externally heat said fuel cylinders in said casing.

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2. The fuel tank according to claim 1, wherein said fuel cylinder has a double wall cylinder composed of an outer cylinder section and an inner cylinder section, a cover member provided at one end thereof and sealingly closed at the one end thereof and in communication with the interior of said inner cylinder section at the other end thereof.

3. The fuel tank according to claim 2, wherein said inner cylinder section is formed with a number of ultrafine pores for guiding the hydrogen gas to be absorbed and desorbed by the hydrogen storage alloy.

4. The fuel tank according to claim 2, wherein the openings of said fuel cylinders are respectively connected to a plurality of conduits which communicate with the post members of said header and are arranged horizontally between the post members of said header.

5. The fuel tank according to claim 2, wherein a connector member is projected from the cover member at one end of said fuel cylinder, engaged with a recess formed on the side wall of said casing, and supported in said casing by integrally forming the conduit arranged between the post members of said header with the connector member of the other end of said fuel cylinder.

6. The fuel tank according to claim 1, wherein said hydrogen storage alloy is filled between the inner cylinder section and the outer cylinder section.

7. The fuel tank according to claim 1, wherein said header is formed in a gate shape with hollow post members at both sides and disposed in front of said casing.

8. The fuel tank according to claim 1, wherein an exist for exhausting the exhaust gas and air or water for cooling is formed at the side wall of said casing.

9. The fuel tank according to claim 1, wherein the hydrogen storage alloy filled in said fuel cylinder is at least one selected from the group consisting of LaNi<sub>5</sub>, mischmetal alloys, Ti-Zr-Mn-Cr-Cu alloys and Mg light alloys.

10. The fuel tank according to claim 1, wherein the hydrogen storage alloy comprises an acicular aluminum.

11. A fuel supplying system for a hydrogen vehicle having a hydrogen-water engine comprising:

means for supplying hydrogen gas from a fuel supply conduit connected to a header mounted integrally with the fuel tank,

means for supplying the hydrogen gas from the openings of a plurality of fuel cylinders into the interiors of the inner cylinder sections of the fuel cylinders to allow the hydrogen gas to be absorbed to hydrogen storage alloy filled between the outer cylinder section and the inner cylinder sections of the respective fuel cylinders through ultrafine pores formed at the inner cylinder sections, said hydrogen storage alloy being selected from the group consisting of LaNi<sub>5</sub>, mischmetal alloys, Ti-Zr-Mn-Cr-Cu alloys and Mg light alloys,

means for supplying air or water from an engine exhaust gas passage into a casing for said fuel cylinders when supplying the hydrogen to the fuel cylinders while cooling the fuel cylinders from the exterior,

means for closing the fuel supply conduit of the heater after filling the fuel cylinders with a predetermined amount of hydrogen gas, and

means for supplying the hydrogen gas to the hydrogen water engine to drive the engine, introducing the exhaust gas generated thereby into the fuel tank to heat the fuel tank and continuously driving the engine by exhausting the hydrogen from the hydrogen storage alloy in the fuel cylinder.

\* \* \* \* \*



# United States Patent [19]

## Emelock

[11] **Patent Number:** **4,597,363**  
 [45] **Date of Patent:** **Jul. 1, 1986**

### [54] HYDROGEN GENERATOR FOR MOTOR VEHICLE

[76] **Inventor:** Melvin Emelock, 1748 NW. 72nd Ave., Plantation, Fla. 33313

[21] **Appl. No.:** 472,987

[22] **Filed:** Apr. 20, 1983

### Related U.S. Application Data

[62] Division of Ser. No. 238,934, Feb. 27, 1981, Pat. No. 4,376,097.

[51] **Int. Cl.<sup>4</sup>** ..... F02B 43/08

[52] **U.S. Cl.** ..... 123/3; 123/DIG. 12; 123/1 A; 422/189; 429/17

[58] **Field of Search** ..... 123/1 A, 3, DIG. 12; 429/17; 48/61, 197 R, 197 A; 422/189; 290/17; 180/65 B

### [56] References Cited

#### U.S. PATENT DOCUMENTS

583,104 5/1897 Wattles ..... 123/1 R X  
 1,790,635 1/1931 Arendt ..... 290/17  
 4,018,190 4/1977 Henault ..... 123/DIG. 12  
 4,119,862 10/1978 Gocho ..... 180/65 B X

*Primary Examiner*—E. Rollins Cross

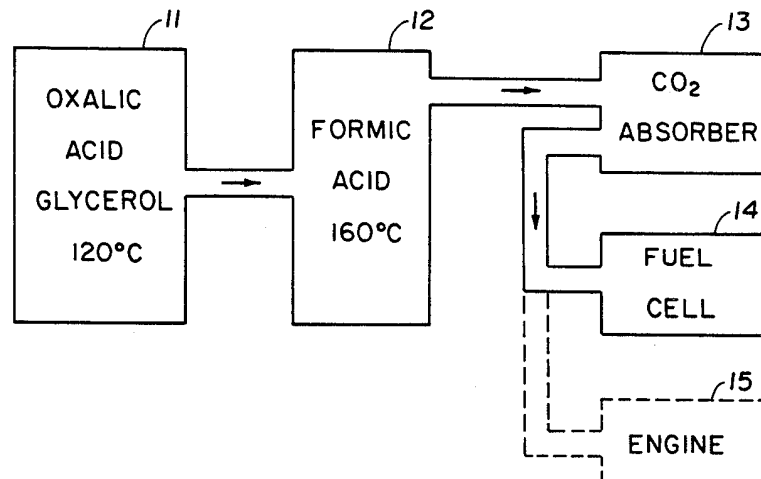
*Attorney, Agent, or Firm*—Joseph Zallen

### [57]

#### ABSTRACT

Oxalic acid, dispersed in glycerol is heated to form formic acid which is then heated at a higher temperature to form hydrogen. By-product carbon dioxide is absorbed. The hydrogen is used directly with a fuel cell to produce electricity or as fuel for an internal combustion engine.

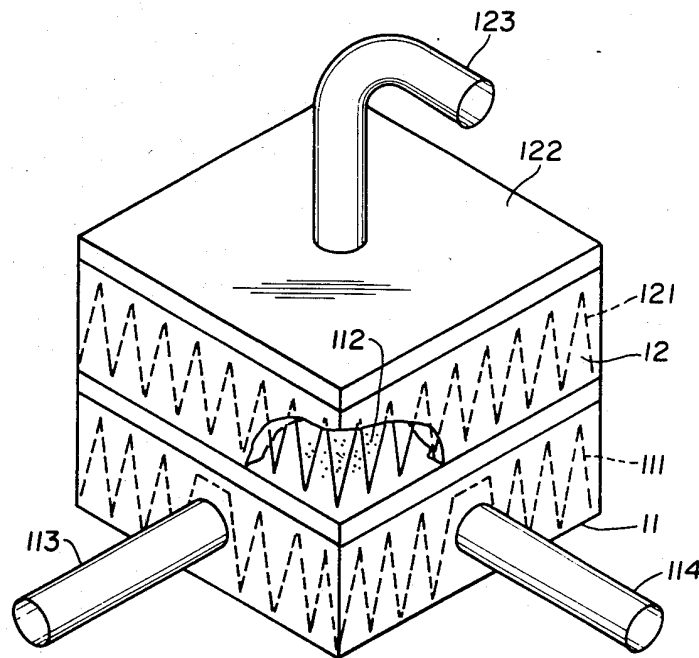
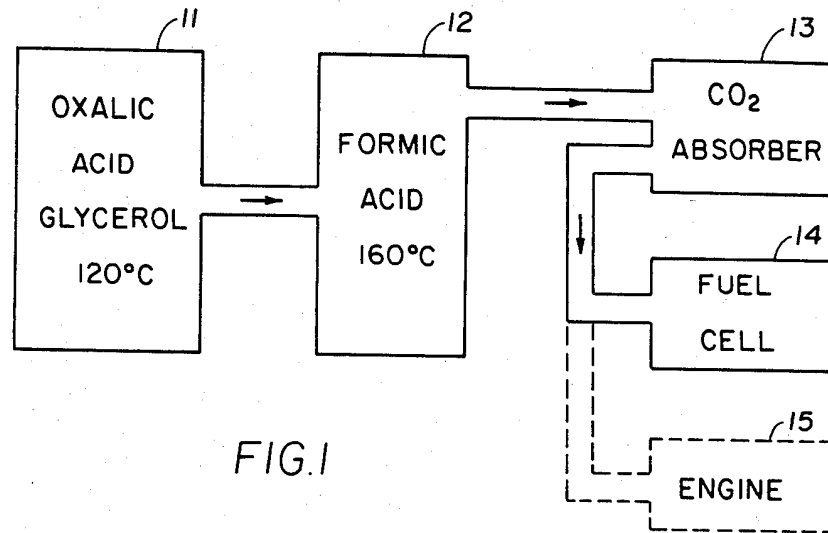
**2 Claims, 2 Drawing Figures**



U.S. Patent

Jul. 1, 1986

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## HYDROGEN GENERATOR FOR MOTOR VEHICLE

This is a division of application Ser. No. 238,934 filed Feb. 27, 1981 now U.S. Pat. No. 4,376,097.

### BACKGROUND OF INVENTION

This invention relates to hydrogen generators. In particular it relates to hydrogen generators which are such size and weight as to be suitable for use in motor vehicles and the like.

As early as 1897 it was proposed to generate hydrogen as a fuel for an engine by reacting zinc or iron with sulphuric acid (U.S. Pat. No. 583,104). It has also been hitherto proposed to have an electric motor vehicle wherein an internal combustion engine drives a generator which in turn maintains the charge on the batteries for the electric motor vehicle (U.S. Pat. Nos. 1,970,634, 1,790,635, 3,517,766 and 4,119,862.) An electric vehicle has also been described in which an internal combustion engine drives an electric generator which in turn directly drives electric motors (U.S. Pat. No. 3,107,304). It has also been proposed to provide an internal combustion engine incorporated with a hydrogen generator wherein alcohol such as methanol is decomposed at a temperature of 200° to 400° C. in the presence of a catalyst such as zinc oxide-copper oxide. For a variety of reasons none of the prior art hydrogen generators are commercially feasible for motor vehicles.

One object of the present invention is to provide a novel hydrogen generator which is feasible for use in a motor vehicle.

Other objects and advantages of this invention will be apparent from the description and claims which follow taken together with the appended drawings.

### SUMMARY OF INVENTION

The hydrogen generator of the present invention utilizes a solid fuel, namely oxalic acid. The oxalic acid preferably in a liquid medium such as glycerol, is heated to form formic acid gas which in turn is heated to form hydrogen.

The reaction of heating oxalic acid forms carbon dioxide as a by-product and the heating of the formic acid gas also forms carbon dioxide as a by-product. Accordingly, one feature of this invention is to separate the carbon dioxide gas from the hydrogen gas as for example, by absorption in an alkaline solution such as calcium hydroxide.

The invention comprises broadly heating a mixture of oxalic acid and glycerol at a temperature of approximately 120° C., whereby formic acid and carbon dioxide are formed, heating the formic acid to a temperature of approximately 160° C. whereby hydrogen gas and carbon dioxide are formed, and conducting the hydrogen to either an internal combustion engine or a fuel cell. Where the hydrogen is conducted to an internal combustion engine it is preferred that the engine be stationary and constantly running so as to operate an electrical generator to maintain the charge in the battery. Where the hydrogen is conducted to a fuel cell it is contemplated that the current produced is fed directly to storage batteries, there preferably being a plurality of fuel cells to obtain the required voltage.

In one embodiment of this invention replaceable cartridges of oxalic acid are placed in a chamber where circulating glycerol conducts the mixture to the first

reaction chamber where the temperature is about 120° C. The formic acid formed in the first reaction chamber is then conducted to the second reaction chamber where at a temperature of 160° C. the hydrogen is formed. The first reaction chamber preferably has a heat-resistant gas permeable membrane so that the gases can escape without affecting the recirculation of the glycerol solution. The carbon dioxide is preferably separated from the hydrogen by absorption as for example, in a chamber of calcium hydroxide solution to form a precipitate of calcium carbonate.

The fuel cell that is preferred for use with this invention is one where the hydrogen does not have to be pure and where air could be used instead of pure oxygen. Carbon electrodes can be used because of the durability and a platinum type catalyst can be used to catalyze the reaction.

Heating of the reaction chambers can be done by the use of thermostatically-controlled electrical heating units within the walls of the reaction chambers. Alternately where an internal combustion engine is used the heat from the exhaust of the engine can be used to accomplish the chemical reactions. A vacuum pump is preferred to insure the removal of the gases from the second reaction chamber.

A preferred use of the invention is in connection with an electric vehicle powered by storage batteries. The oxalic acid fuel provides the energy for additional recharging of the batteries and thus can be operated on a steady basis on a vehicle.

The construction of the device is illustrated schematically.

It is well within the scope of the chemical engineering art of today to select the appropriate materials, sizes and shapes of the materials of construction, sizes, arrangement and shapes of the various chambers and other components of the invention.

### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram of the invention.

FIG. 2 is a schematic diagram of a hydrogen generator made in accordance with this invention.

### SPECIFIC EXAMPLES OF INVENTION

Referring to the drawings, the oxalic acid dispersed in glycerol heated to 120° C. yields formic acid and carbon dioxide. The formic acid which is gaseous in form when now heated to 160° C. forms hydrogen gas and carbon dioxide. The carbon dioxide from both stages is absorbed and the hydrogen gas fed to either a fuel cell or an engine.

Oxalic acid dispersed in glycerol is placed in enclosed chamber 11 which has all solid walls except for the top wall 112 which is a gas-permeable, inert, heat-resistant membrane, as for example, fiberglass or ceramic. The walls of chamber 11 contain thermostatically controlled electric heaters which maintain the temperature of chamber 11 at approximately 120° C. Conduits 113 and 114 permit a continuous flow of oxalic acid and glycerol into chamber 11 from a source not illustrated.

As the oxalic acid decomposes into formic acid gas, the gas passes through membrane wall 112 to the second chamber 12 where thermostatically controlled electric heaters in its walls maintain the temperature of chamber 12 at approximately 160° C. The formic acid decomposes to form hydrogen gas. The hydrogen is passed through carbon dioxide absorber 13 and then fed to

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either a fuel cell 14 or as fuel to internal combustion engine 15.

The gases exit chamber 12 through exit conduit 123, to which a vacuum may be applied. The carbon dioxide absorber 13 may contain a slurry of calcium hydroxide. Although not illustrated it is contemplated that the recirculating glycerol, will be bringing in fresh oxalic acid in chamber 11 to replace the oxalic acid consumed, so that this is a controllable reaction. The hydrogen produced can be fed to fuel cells of various construction, but preferable those that do not require high purity as for example, a fuel cell utilizing aqueous sulphuric

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acid with carbon electrodes and a platinum-type catalyst.

I claim:

1. A method for generating electricity in situ comprising heating a dispersion of oxalic acid in liquid medium at about 120° C. to form formic acid, heating said formic acid at a temperature of about 160° C. to form hydrogen, and conducting said hydrogen to a fuel cell whereby electrical energy is formed or as fuel to an internal combustion engine.

2. The method of claim 1 wherein the liquid is glycerol.

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# United States Patent [19]

**Lewis**

[11] **Patent Number:** **4,622,924**  
 [45] **Date of Patent:** **Nov. 18, 1986**

[54] **HYDROGEN ENGINE**

[76] **Inventor:** William N. Lewis, Rte. 4, Box 1090,  
Baxley, Ga. 31513

[21] **Appl. No.:** 505,781

[22] **Filed:** Jun. 20, 1983

[51] **Int. Cl.<sup>4</sup>** ..... F02B 43/08

[52] **U.S. Cl.** ..... 123/3; 123/DIG. 12;  
423/652

[58] **Field of Search** ..... 123/1 A, 3, DIG. 12,  
123/196 AB; 60/649; 423/648 R, 657, 658, 652,  
650

[56] **References Cited**

**U.S. PATENT DOCUMENTS**

1,619,978 3/1927 Hunt ..... 123/196 AB  
 3,904,744 9/1975 Pagel ..... 423/652

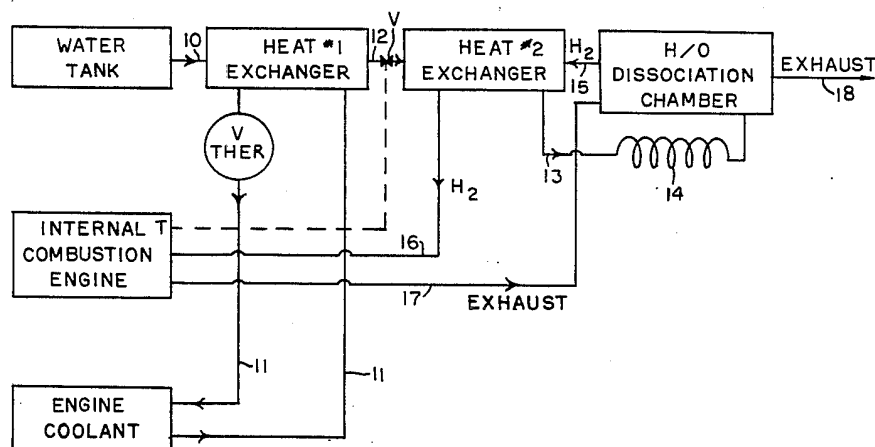
3,968,775 7/1976 Harpman ..... 123/3  
 3,992,165 11/1976 Newkirk ..... 123/3  
 4,003,343 1/1977 Lee ..... 123/3  
 4,036,181 7/1977 Matovich ..... 123/3  
 4,037,568 7/1977 Schreiber ..... 123/3  
 4,099,489 7/1978 Bradley ..... 123/3  
 4,220,518 9/1980 Uchida et al. .... 423/658  
 4,380,970 4/1983 Davis ..... 123/3

*Primary Examiner*—William A. Cuchlinski, Jr.  
*Attorney, Agent, or Firm*—Thomas & Kennedy

[57] **ABSTRACT**

Hydrogen and oxygen are dissociated from water by converting water to steam and contacting the steam with resin or oil. Hydrogen is fed as it is dissociated into an internal combustion engine for combustion.

**10 Claims, 3 Drawing Figures**



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Sheet 1 of 2

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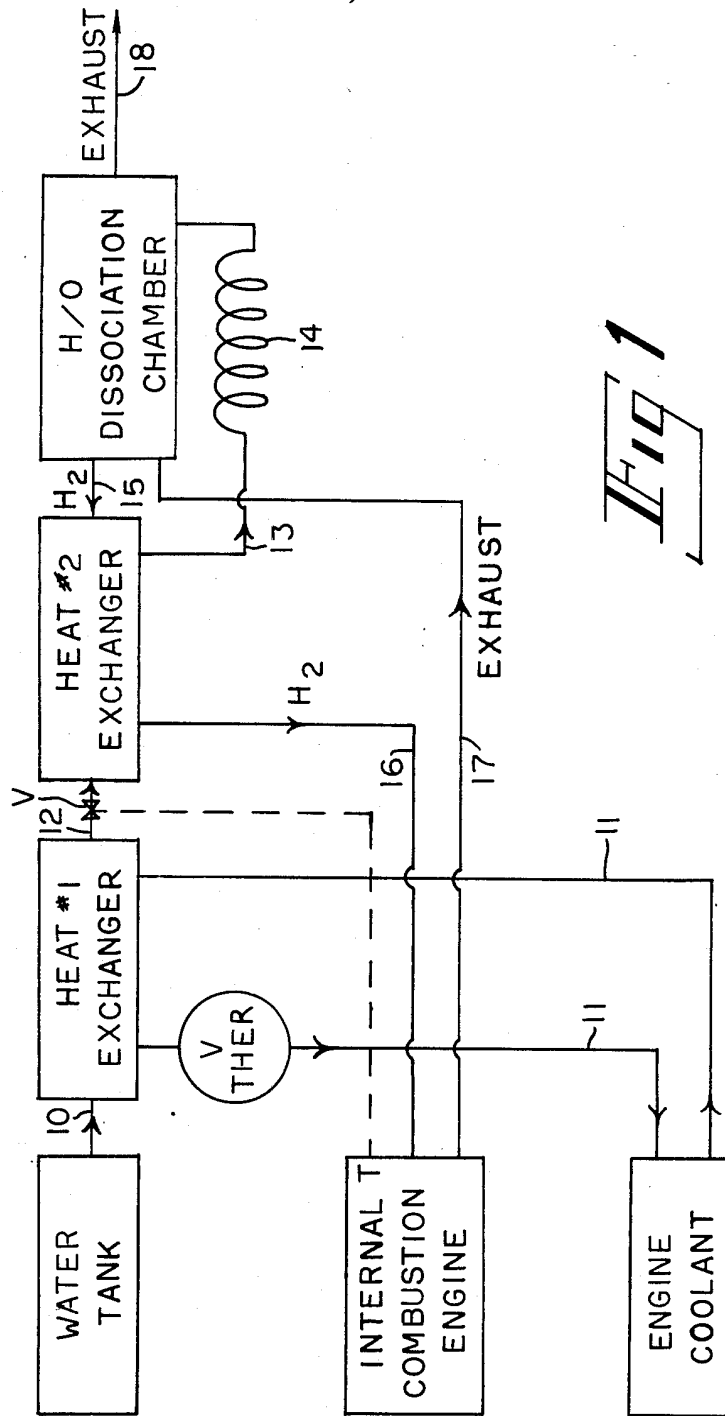
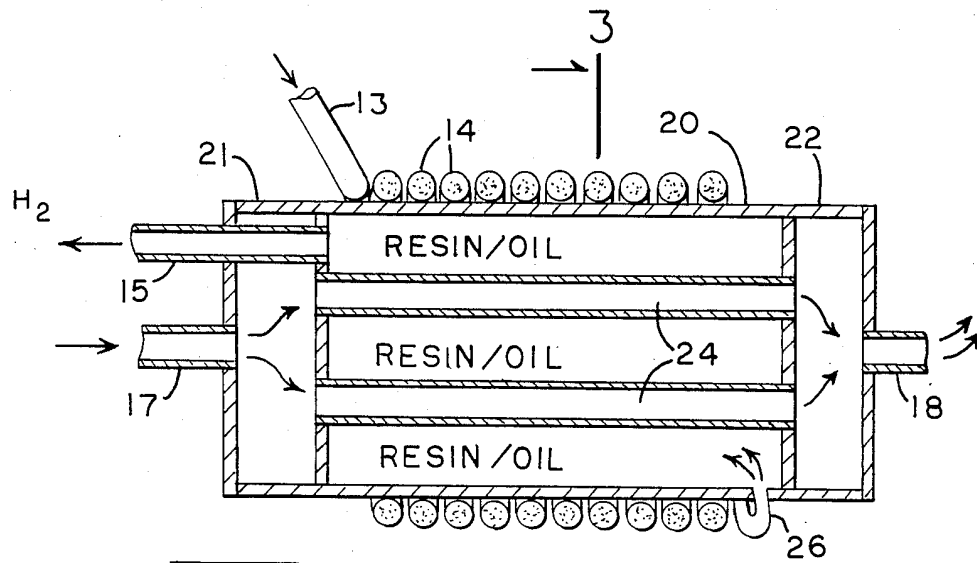
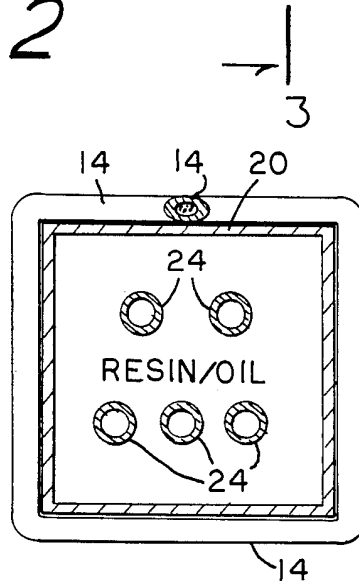


Fig. 1

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*Fig* 2



*Fig* 3

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## HYDROGEN ENGINE

### TECHNICAL FIELD

This invention relates to methods and apparatuses for generating hydrogen and for utilizing hydrogen as a fuel for internal combustion engines.

### BACKGROUND OF THE INVENTION

Upon combustion hydrogen releases a substantial amount of energy which may be utilized in the generation of power. However, since it is a chemically active element and therefore not available in the free state in nature in elemental gaseous form, it must be produced and stored for utilization in engines.

In general, hydrogen is obtained from compounds by breaking chemical bonds. This, of course, requires a substantial amount of energy to accomplish. Though there are many ways of liberating hydrogen from hydrocarbons, acids, bases and water, it is usually obtained in commercial quantities from water or petroleum. From hydrocarbons a mixture of methane and steam is typically heated to a high temperature in the presence of catalysts in producing large quantities of hydrogen. From water hydrogen is produced by electrolysis.

Methods of producing hydrogen are more specifically exemplified in U.S. Pat. Nos. 3,699,718, 3,786,138, 3,816,609, 3,859,373, 4,069,304 and 4,202,744. These methods generally include steam-light hydrocarbon reforming, partial oxidation of hydrocarbons and other carbonaceous matter, and coal gasification (the Kellogg process).

To date, hydrogen engines have had only very limited and specialized use, such as in propelling rockets and missiles and other military applications. They have not found general use as power sources for driving vehicles over public roads for a number of reasons. Probably foremost among such reasons is the danger associated with the use of hydrogen for its propensity to combust and release vast amounts of energy in violent reactions. To transport gaseous hydrogen in a storage tank in vehicles would thus create a very substantial danger to the motoring public. Another reason is that the expense and storage space requirements involved are too high where hydrogen is to be produced from hydrocarbons such as methane. Liquid water would not, of course, present a storage or expense problem. However, the rate by which hydrogen could be produced from water by electrolysis would be insufficient for use as an automotive engine fuel.

Accordingly, it is to the provision of methods and apparatuses for producing hydrogen and utilizing it as it is generated as a fuel in internal combustion engines to which the present invention is primarily directed.

### SUMMARY OF THE INVENTION

In one form of the invention, a gas generation process comprises the steps of forming a stream of steam at a temperature of between 500° F. and 900° F. and passing the stream through a body of oil or resin whereupon the stream of steam is at least partially dissociated into hydrogen and oxygen.

In another form of the invention a power generation process comprises the steps of forming a stream of steam at a temperature of between 500° F. and 900° F., contacting the stream with resin or oil whereupon hy-

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drogen is dissociated from oxygen, and igniting the hydrogen.

In another form of the invention a power generation process is provided wherein hydrogen is generated and used as engine fuel at substantially the same rates of generation and fuel utilization so that hydrogen storage may be substantially avoided. The process comprises the steps of introducing water into a hydrogen-oxygen dissociation apparatus through valve means controlled by an engine throttle, dissociating hydrogen and oxygen in the dissociation apparatus, and feeding the hydrogen as it is being generated into the engine.

In yet another form of the invention, a power generation system comprises an internal combustion engine, a fuel tank adapted to hold a supply of water, and a hydrogen-oxygen dissociation chamber containing a supply of oil or resin. The system further includes first conduit means for feeding water from the fuel tank to the hydrogen-oxygen dissociation chamber, heating means for converting water being fed through the conduit means from a liquid to a gaseous phase, and second conduit means for feeding hydrogen generated in the hydrogen-oxygen dissociation chamber to the internal combustion engine for combustion therein.

In still another form of the invention apparatus for dissociating hydrogen and oxygen comprises a chamber housing oil or resin and conduit means passing through the chamber through which hot gases may be passed to heat the oil or resin. A pipe is thermally coupled and placed in communication with the chamber which pipe contains a mass of particulates into which water may be fed and phase changed into steam upon contact with particulates that have been heated by thermal conduction from the chamber and the steam passed into the chamber and into contact with the oil or resin.

### BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram of a system embodying principles of the invention which may be used in practicing processes of the invention.

FIG. 2 is a cross-sectional view of apparatus for dissociating hydrogen from oxygen in accordance with principles of the invention.

FIG. 3 is a cross-sectional view taken along plane 3—3 of the apparatus illustrated in FIG. 2.

### DETAILED DESCRIPTION

With reference to the schematic diagram presented in FIG. 1, a hydrogen engine that includes a hydrogen generation system is seen to include an internal combustion engine such as that conventionally used in powering an automotive vehicle which has a throttle T and which is water cooled with a conventional engine coolant system. A fuel tank is provided which houses a supply of water. A conduit 10 extends from the water tank to a first heat exchanger that is coupled with the engine coolant system via a system of conduits 11 in which a thermionic valve is employed. A conduit 12 extends from the first heat exchanger in fluid communication with conduit 10 to a second heat exchanger through a valve V that is coupled with and controlled by the internal combustion engine throttle T. Another conduit 13 extends from the second heat exchanger in fluid communication with conduit 12 to a convoluted conduit 14 which is in fluid communication with a hydrogen-oxygen dissociation chamber. A conduit 15 extends from the dissociation chamber back to the second heat exchanger in fluid communication with an-



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other conduit 16 that extends from the second heat exchanger to the internal combustion engine. Within the internal combustion engine itself the conduit 16 is connected to the carburation or fuel injection subsystem. Finally, another conduit 17 extends from the engine exhaust system of the internal combustion engine to the dissociation chamber and into communication with an exhaust pipe 18.

With reference next to FIGS. 2 and 3 the hydrogen-oxygen dissociation chamber is seen to include a tank 20 to one end of which an intake manifold 21 is secured and to the opposite end of which an outlet manifold 22 is secured. Five pipes 24 extend through the tank 20 between the two manifolds. The conduit 17 is seen to be connected with the intake manifold while the tail pipe 18 is coupled with the outlet manifold. The conduit 13 is seen to merge into the convoluted form of the conduit 14 which is wrapped tightly around the tank 20 so as to be thermally coupled with it. Within the convoluted conduit 14 is packed a mass of particulates such as common iron-bearing rocks. The end of the convoluted conduit is provided with an elbow joint 26 through which fluids may be inputted into the bottom of the tank 20.

The conduit 15 is seen to extend from the tank 20 through the intake manifold to the second heat exchanger. The tank 20 houses a supply of resin or oil. Various kinds of oils may be employed such as mineral oils and petroleum oils. The preferred resin is a gum or pine tar resin although soybean oil may also be used. The gum resin may be obtained from Southern, yellow or long-leaf pine trees.

Prior to operation the resin or oil within the hydrogen-oxygen dissociation chamber is preheated to a temperature of between 500° F. and 900° F. as by the use of an unshown auxiliary preheat means of conventional construction. The temperature of the resin should be at least 500° F. since below that temperature efficiency goes down in that an insufficient quantity of hydrogen is generated. Conversely, above approximately 900° F., depending upon the particular resin or oil employed, that resin or oil may tend to break down into another state.

Once the resin or oil has achieved the proper temperature the engine is operated in the following manner. Water is fed as by unshown pump means from the water tank to the dissociation chamber through the conduits 10, 12 and 15, the two heat exchangers and the valve V. In passing through the first heat exchanger the water is preheated from the heat of the engine coolant. The water is then fed through the valve V to the second heat exchanger with the valve V being controlled by the position of the engine throttle T. From the second heat exchanger the water is fed through conduit 13 and into the convoluted pipe 14 where it comes into contact with the heated mass of particulates and is converted to a low pressure stream of steam. From here the low pressure stream of steam passes slowly through the body of resin or oil within the hydrogen dissociation chamber. Upon contact with the resin or oil the steam is dissociated into hydrogen and oxygen.

From the dissociation chamber the dissociated hydrogen and oxygen passes through a conduit 15 to the second heat exchanger wherein the hydrogen is cooled down somewhat from its 600° F. temperature. The hydrogen is then fed directly through conduit 16 into the fuel intake system of the engine where it is ignited to produce energy in driving the internal components of

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the engine. The heat from the exhaust passes through the conduit 17 and into the intake manifold 21 and through pipes 24 within the tank 20 and from there through the outlet manifold to the tail pipe 18. This heat is transmitted to the body of resin or oil in maintaining its proper temperature.

It is not fully understood how hydrogen and oxygen is dissociated with the just-described system since the temperatures involved are substantially less than that previously thought necessary to produce the energy levels required in breaking the oxygen-hydrogen bond. Apparently the low pressure stream of steam, however, when brought into contact with the surface of the resin or oil, is catalyzed in some manner so that the required temperature to produce the necessary energy is lowered. In any event, the system and process has been found to work well in propelling automobiles over roads solely with a supply of water being used as the engine fuel in addition to the supply of resin and oil, and the use of an auxiliary preheating system.

#### OPERATIVE EXAMPLE

The just described power generation apparatus has been successfully used by mounting it upon an approximately 4,000 pound Ambassador model automobile sold by American Motors Corporation with the hydrogen engine's dissociation chamber oriented vertically and less than half filled with 8 pounds of standard grade (Marion) pine resin and with the steam generating pipe filled with iron rocks. The Ambassador's standard 232 cubic inch internal combustion engine was fueled solely with gases generated by the hydrogen engine. The resin and tap water were both heated to approximately 600° F. and water fed to the dissociation chamber at a rate of 1 gal./hour. Steam was developed at 5 pounds/square inch and passed through the resin continuously for a period of approximately 2 hours while the automobile was being driven upon public roads at an average speed of 60 miles per hour. The temperature of the steam was found to drop from approximately 600° F. to approximately 500° as it passed through the second heat exchanger. Water was consumed at a rate of approximately 1 gal./hour and resin consumed at a rate of approximately  $\frac{1}{2}$  pound/hour.

It should be understood that the just-described embodiment merely illustrated principle of the invention in one particular form. Many modifications, additions or deletions may, of course, be made thereto without departure from the spirit and scope of the invention as set forth in the following claims.

I claim:

1. A gas generation process comprising the steps of forming a stream of steam at a temperature of between 500° F. and 900° F. and passing the stream through a body of oil or resin whereupon the stream of steam is at least partially dissociated into hydrogen and oxygen.
2. The gas generation process of claim 1 wherein the stream of steam is passed through a body of gum resin.
3. The gas generation process of claim 1 wherein the stream of steam is passed through a body of pine resin.
4. A power generation process comprising the steps of forming a stream of steam at a temperature of between 500° F. and 900° F.; contacting the stream with resin or oil whereupon hydrogen is dissociated from oxygen; and igniting the hydrogen.
5. The power generation process of claim 4 where the stream of steam is passed through a body of resin.

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6. The power generation process of claim 4 wherein the stream of steam is passed through a body of oil.

7. The power generation process of claim 4 wherein the hydrogen is ignited in an internal combustion engine.

8. A power generation process wherein hydrogen is generated and used as engine fuel at substantially the same rates of generation and fuel utilization so that storage may be substantially avoided, and with said process comprising the steps of introducing water into a hydrogen-oxygen dissociation apparatus through valve means controlled by an engine throttle, dissociating hydrogen and oxygen in the dissociation apparatus by vaporizing the water to steam at a temperature of between 500° F. and 900° F. and contacting the steam with oil or resin, and feeding the hydrogen as it is generated into the engine for combustion therein.

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9. Apparatus for dissociating hydrogen and oxygen comprising a chamber housing oil or resin; conduit means passing through said chamber through which hot gases may be passed to heat said oil or resin; a first pipe in communication with a water tank and thermally coupled and communicating with said chamber, said first pipe containing a mass of particulates into which water may be fed and phase-changed into steam upon contact with particulates that have been heated by thermal conduction from said chamber and the steam passed into the chamber and into contact with the oil or resin; and a second pipe communicating with said chamber through which hydrogen and oxygen dissociated from steam contacted with said oil or resin within said chamber may be conveyed out of said chamber.

10. The apparatus of claim 9 wherein said pipe is convoluted about said dissociation chamber.

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**United States Patent** [19]

Alger

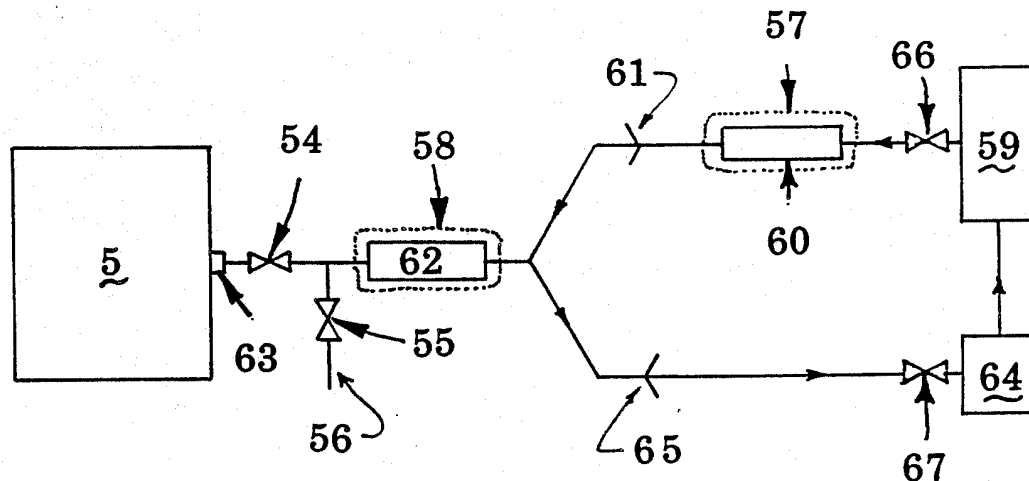
[11] **Patent Number:** **4,651,527**[45] **Date of Patent:** **Mar. 24, 1987**[54] **PROCESS AND APPARATUS FOR  
REDUCING THE LOSS OF HYDROGEN  
FROM STIRLING ENGINES**[76] **Inventor:** Donald L. Alger, 3419 W. 144th St.,  
Cleveland, Ohio 44111[21] **Appl. No.:** 866,486[22] **Filed:** May 23, 1986[51] **Int. Cl.<sup>4</sup>** ..... F02G 1/04[52] **U.S. Cl.** ..... 60/517[58] **Field of Search** ..... 60/517, 521[56] **References Cited****U.S. PATENT DOCUMENTS**

3,164,493	1/1965	Lindberg	148/6.3
3,732,690	5/1973	Meijer	60/39.46
4,197,707	4/1980	Asano	60/517
4,312,641	1/1982	Verrando et al.	55/33
4,335,884	6/1982	Darche	277/3

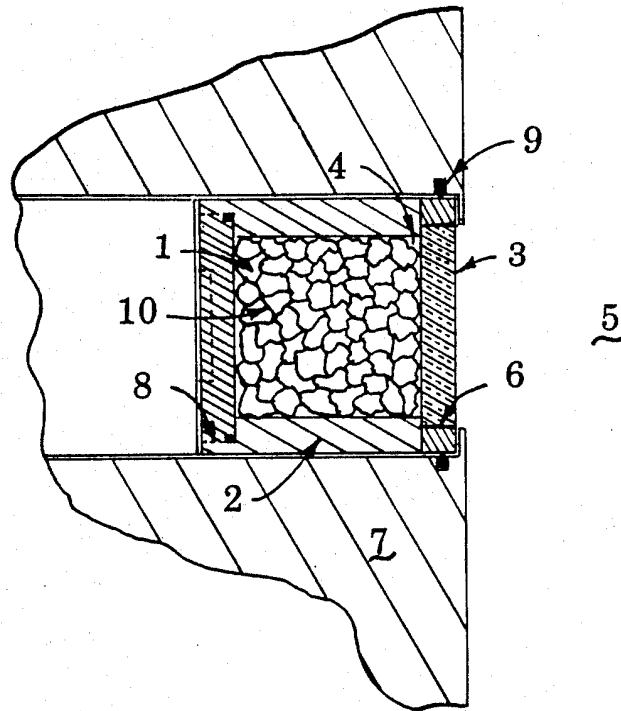
*Primary Examiner*—Allen M. Ostrager*Attorney, Agent, or Firm*—Fay, Sharpe, Fagan, Minnich  
& McKee[57] **ABSTRACT**

A permeation barrier is maintained on inner surfaces of a Stirling engine, particularly the heat tubes, by maintaining a preselected concentration of dopant gas in the

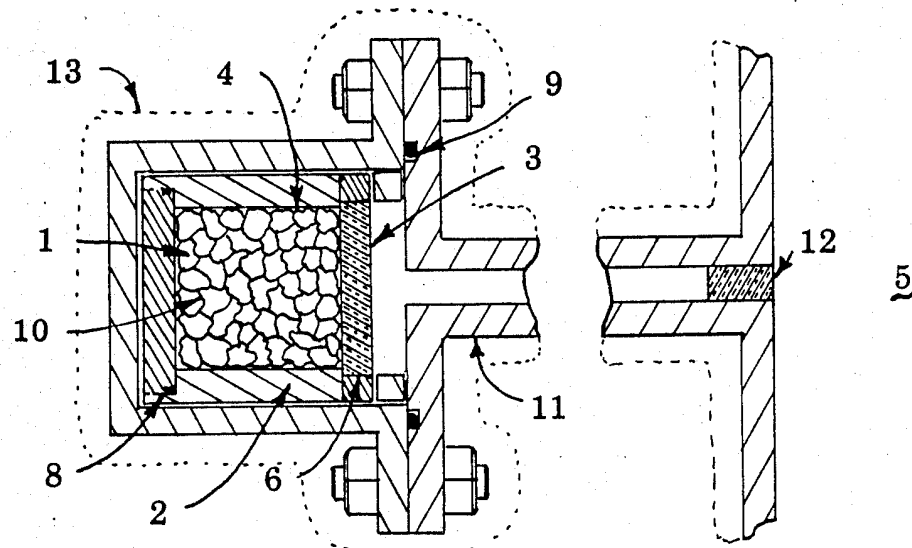
working gas, e.g. hydrogen. A dopant gas (10) is adsorbed on a sorbent (1) in a dopant cartridge or enclosure (2). The amount of gas adsorbed, the quantity of sorbent, and the permeability of a permeable window (3) are selected such that a preselected partial pressure of the dopant is maintained in the hydrogen. In a diffusion cell (FIGS. 1 and 2) an equilibrium partial pressure of the dopant gas is maintained by diffusion through the porous window. In a flow-through cell (FIGS. 3–5) the hydrogen or working gas is circulated through the sorbent. A fraction of the adsorption sites on the sorbent may be left open to adsorb excess water vapor from the hydrogen. In a trap cell (FIGS. 9 and 10) water vapor is removed from the working gas as the working gas is pumped by a compressor into a high pressure storage reservoir (59). An appropriate partial pressure of water vapor dopant is reintroduced into the hydrogen as the hydrogen passes from the high pressure reservoir through the trap cell back into the working volume of the Stirling engine. To facilitate handling of the activated sorbent cells without exposing the sorbent to contaminants, a collapsible barrier (29, 42) is provided for automatically isolating the sorbent when the cell is exposed to the atmosphere.

**20 Claims, 10 Drawing Figures**

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**FIGURE 1**

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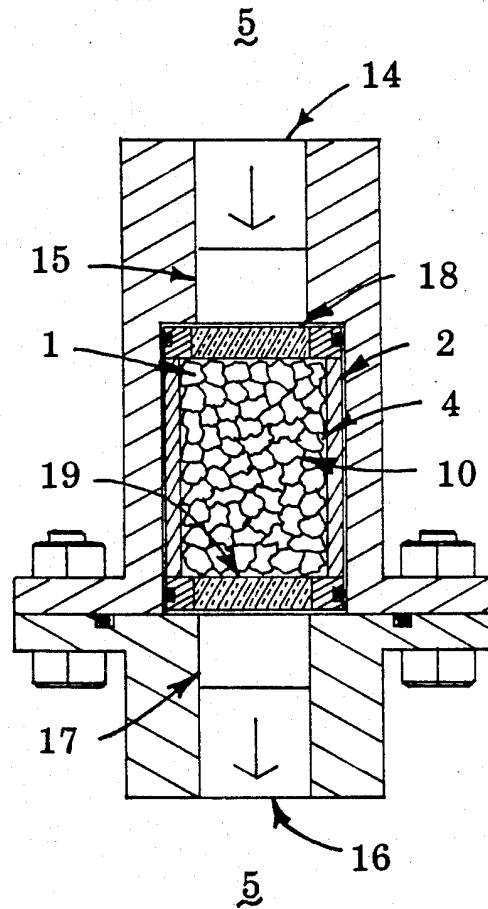


FIGURE 3

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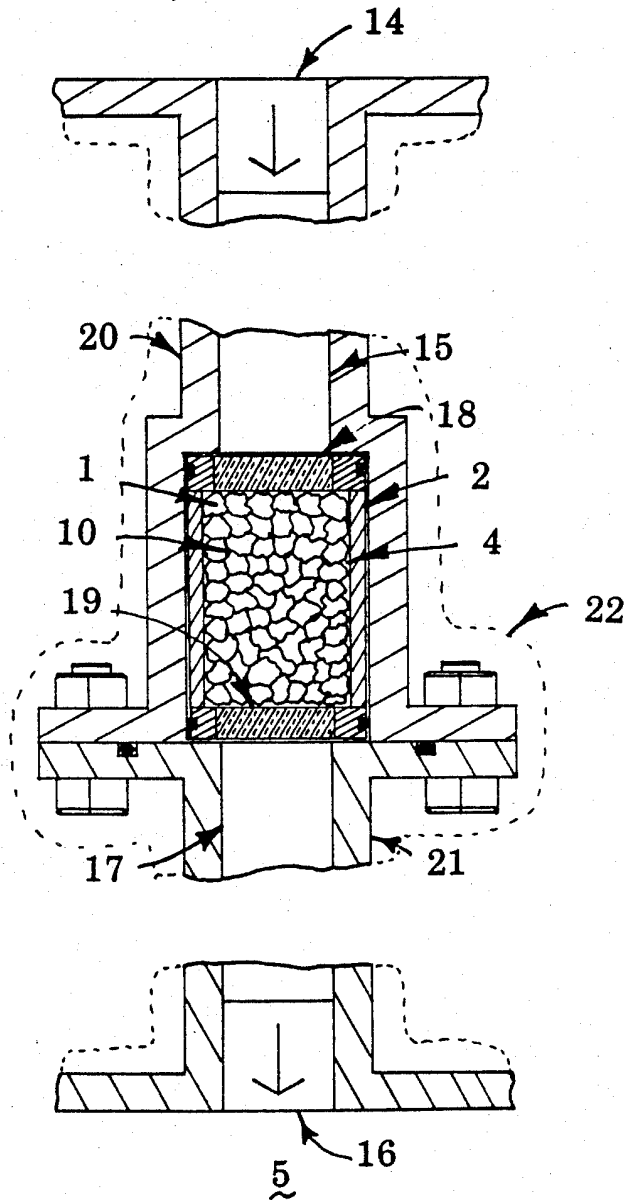


FIGURE 4

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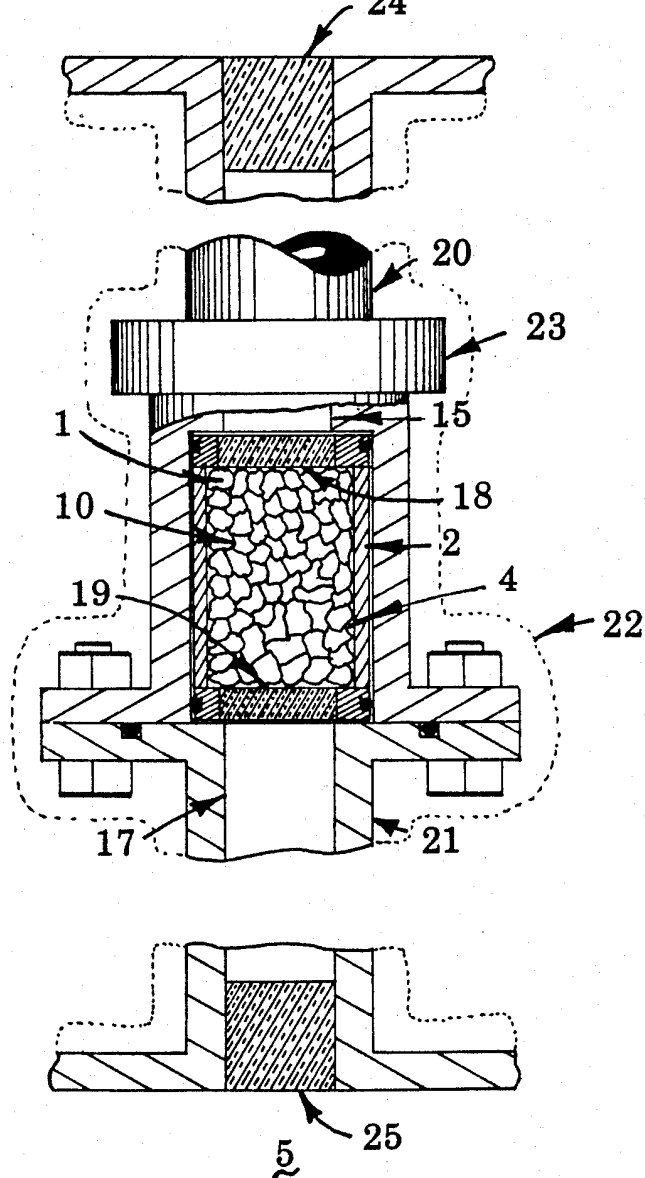
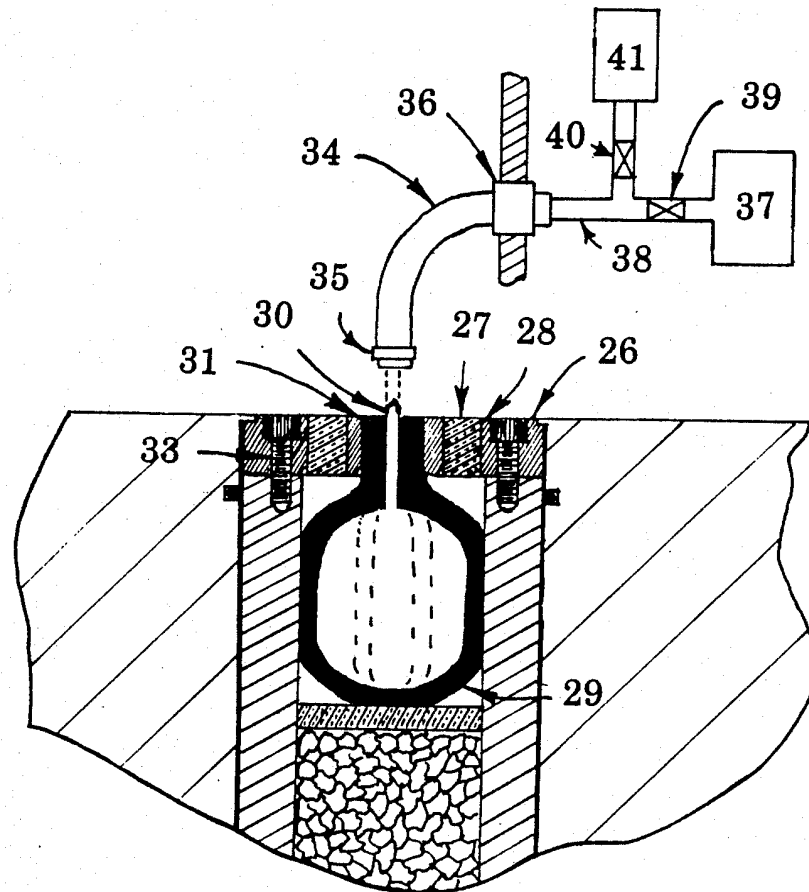


FIGURE 5



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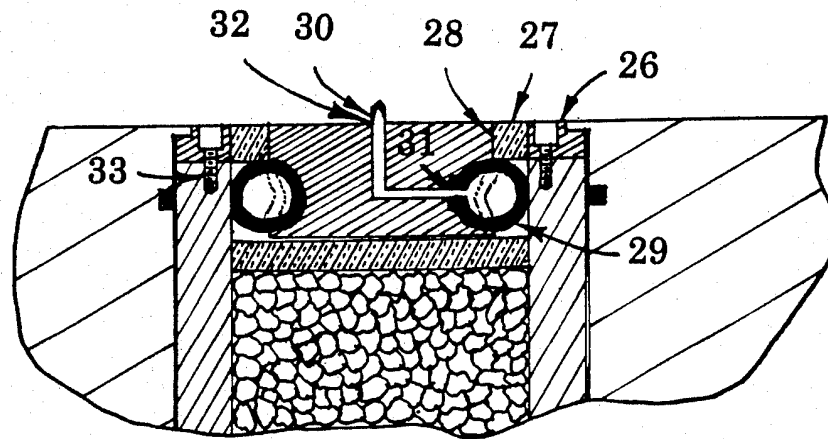


FIGURE 7

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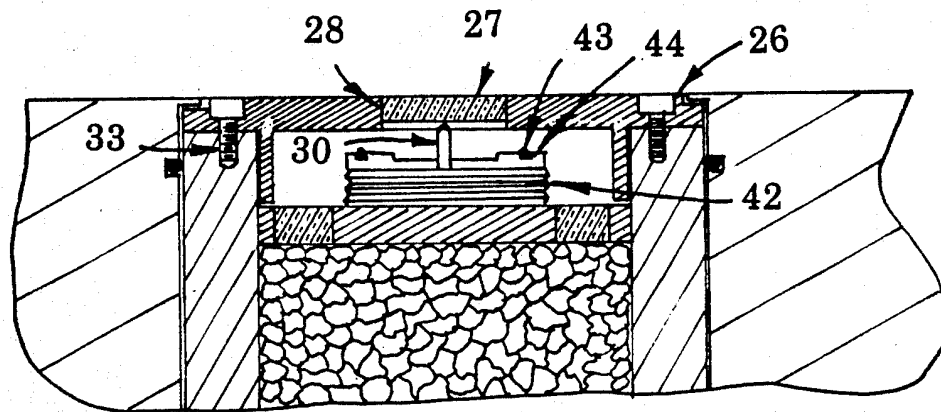
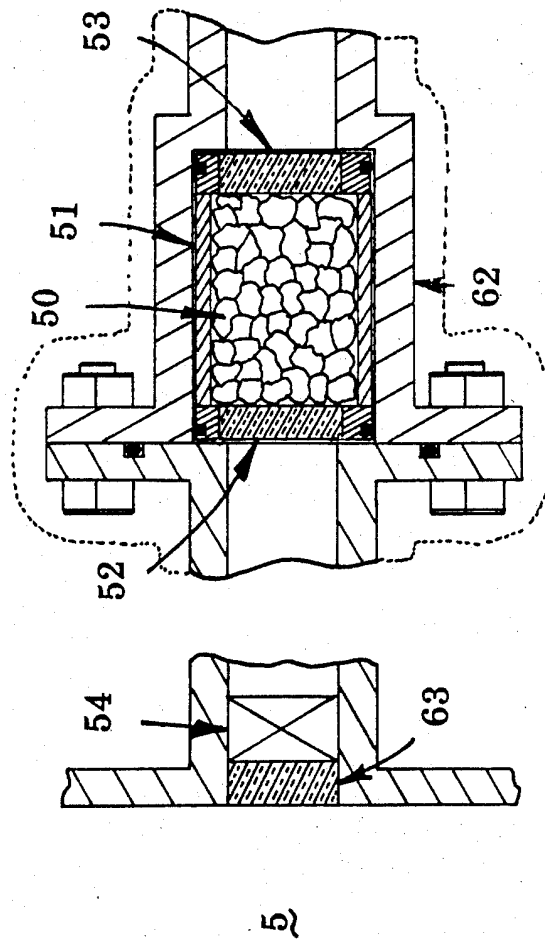


FIGURE 8

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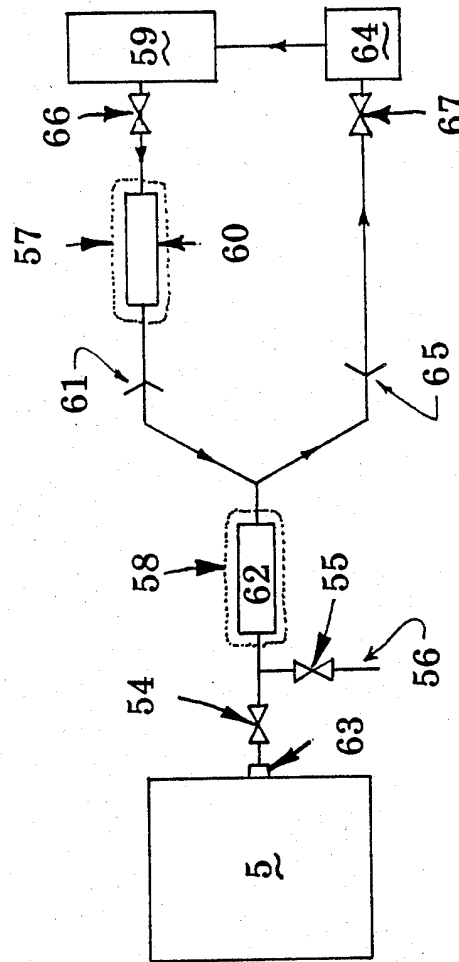


FIGURE 10

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## PROCESS AND APPARATUS FOR REDUCING THE LOSS OF HYDROGEN FROM STIRLING ENGINES

### BACKGROUND OF THE INVENTION

The present invention relates to the art of gas permeation reduction. It finds particular application in conjunction with reducing hydrogen loss in Stirling engines by establishing and maintaining a hydrogen permeation barrier on the inner surface of the engine heat tubes and will be described with particular reference thereto. However, it is to be appreciated that the present invention will have other applications particularly where hydrogen or other highly permeable gases function as the working fluid.

Stirling engines achieve the greatest efficiency with a low molecular weight gas for the working medium, e.g. hydrogen or helium. The relative rarity and high cost of helium gas render its use impractical for commercial engines in which a large volume of working medium or gas would be required. Hydrogen, which is both more abundant and lower in molecular weight than helium, readily permeates the metal alloys and other materials of which Stirling engines are commonly constructed. The loss of hydrogen by permeation through these metal alloys at the relative high temperature and pressures of a Stirling engine are generally considered to be unacceptably high.

A relatively small partial pressure of carbon dioxide, carbon monoxide, or water vapor as a dopant has been found to be effective in reducing the loss of hydrogen by permeation. However, the temperature and pressure variations within a Stirling engine are sufficiently great that the water vapor tends to condense in the cooler regions of the engine. The condensed water vapor causes severe mechanical and corrosion problems. During the engine cycle, the carbon dioxide and monoxide dissociate, freeing oxygen which combines with the hydrogen to form additional water vapor. The increasing concentration of water vapor, again, condenses in regions of lower temperature or higher pressure.

Commonly, carbon monoxide and carbon dioxide are effective in reducing hydrogen permeation over a partial pressure range of 0.1 to 1.0%. To avoid condensation problems, the water vapor must be present in partial pressures that are sufficiently low that condensation is avoided. The exact partial pressure, of course, varies with the operating temperature and pressure of the engine. However, partial pressures which are lower than 0.1% are normally required.

Other approaches for reducing hydrogen loss are illustrated in U.S. Pat. No. 4,197,707 issued Apr. 15, 1980 to Kenji Asano, which has a recovery system for recapturing lost hydrogen which has escaped from the system. U.S. Pat. No. 4,335,884 issued June 22, 1982 to Michael Darche limits hydrogen loss between the pistons and cylinder walls through the use of flexible or rolling diaphragms. Both of these techniques, however, are limited in their ability to stop hydrogen loss.

In accordance with the present invention, a method and apparatus is provided for accurately maintaining dopant levels in the working fluid of Stirling engines and the like.

### SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, a method is provided for maintaining a selected

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dopant gas concentration in the working gas of a Stirling engine. A selected dopant is adsorbed on an activated sorbent. The dopant adsorbed sorbent is connected in gaseous communication with the working gas of the Stirling engine. The dopant adsorbed sorbent and its interconnection with the Stirling engine are configured such that a preselected equilibrium partial pressure is maintained between the dopant and working gases.

In accordance with another aspect of the present invention, a Stirling engine is combined with a source of dopant gas. The dopant gas source includes a hermetic enclosure which isolates an interior thereof from the atmosphere. An activated sorbent with a dopant adsorbed thereon is disposed within the hermetic enclosure. A gas passing means operatively connects the hermetic enclosure interior and an interior of the Stirling engine such that the dopant and working gases flow therebetween to establish a preselected partial pressure equilibrium.

In accordance with more limited aspects of the present invention, the working gas is hydrogen and the dopant gas is selected from the group of carbon monoxide, carbon dioxide, and water vapor. The sorbent may be any material which appropriately adsorbs the selected dopant, such as a molecular sieve, activated alumina, activated carbon, activated charcoal, siliceous sorbents, zeolites, other carbons, and organic materials including crosslinked polystyrene, porous resin, phenolic, acrylic ester, and cellulose.

In accordance with another more limited aspect of the present invention, the sorbent enclosure is configured as a diffusion cell in which a permeable membrane is disposed between the sorbent and the working gas of the Stirling engine. In another aspect, the enclosure is configured as a flow-through cell in which the working gas flows through the sorbent in the enclosure from an area of high pressure on one side of the enclosure to an area of lower pressure on the other side of the enclosure. In accordance with yet another more limited aspect of the invention, the sorbent removes excess water vapor. This last aspect is particularly advantageous in adding and removing water vapor to working gas as it is discharged from and returned to a high pressure storage reservoir.

A primary advantage of the present invention resides in reduced hydrogen loss from Stirling engines.

Another advantage of the present invention, is that it provides for the accurate control of partial pressures of dopants within a working gas.

Still further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

### BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take form in various steps and arrangements of steps and in various elements and arrangements of elements. The figures are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention. Wherein the figures show:

FIG. 1 illustrates a diffusion cell mounted inside a Stirling engine in accordance with the present invention;

FIG. 2 illustrates a diffusion cell mounted externally to a Stirling engine;

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FIG. 3 illustrates a flow-through cell installed inside a Stirling engine;

FIG. 4 illustrates a flow-through cell configured to be mounted externally of the engine;

FIG. 5 illustrates a flow-through cell which incorporates a blower for causing a pressure differential thereacross in accordance with the present invention;

FIGS. 6, 7, and 8 illustrate self-sealing cells which may be of either the diffusion or flow-through type for sealing the sorbent from the atmosphere when the cell is separated or disconnected from the engine;

FIG. 9 illustrates a trap cell in accordance with the present invention which is configured for external mounting; and

FIG. 10 illustrates a Stirling engine arrangement including a Stirling engine, a reservoir of high pressure hydrogen, and a trap cell in accordance with FIG. 9.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to FIG. 1, an activated sorbent 1 is contained inside a cell container or hermetic enclosure 2 which separates the activated sorbent from the atmosphere. A gas flow means connects the enclosure interior 4 with an engine volume 5. In the preferred embodiment, the gas flow means includes a sintered metal element or window 3 which permits dopant and working gases to pass therethrough. The window 3 is sealed to the enclosure 2 such as by a weld 6 to seal the sorbent 1 in the cells. The enclosure 2 is attached within a Stirling engine 7 in such a manner that good thermal contact is maintained therebetween. Optionally, a threaded cap and seal 8 may be provided to facilitate loading the cell with the sorbent. An O-ring 9 or other appropriate seal prevents the loss of working gas around the cell.

The sorbent 1 has a dopant 10 adsorbed thereon. In one preferred embodiment, the adsorbed dopant is carbon dioxide. More specifically, a sorbent selected from the sorbents listed in Table 1 below is loaded into the enclosure. Adsorbed atmospheric air components are removed from the sorbent, commonly with a combination of heat and vacuum to activate the sorbent. Thereafter, substantially pure carbon dioxide is passed into the enclosure such that the carbon dioxide is adsorbed on the sorbent until the sorbent is saturated. The cell is then sealed from the atmosphere with an appropriate seal across the window to prevent any exchange of the carbon dioxide and atmospheric gases prior to loading of the cell in the Stirling engine. Optionally, interstices between particles of the adsorbent may be filled with hydrogen.

TABLE 1

Sorbent	Trade Name	Surface Area, m/gm
<b>SILICEOUS SORBENTS</b>		
Aluminosilicates	Molecular sieves, Linda 3A, 4A, 5A, 10X, 13X, AW-300, AW-500, etc.	600-800
Silica gel	Davison Silica gel, Cecagel, Sorbsil, etc.	300-800 650-900
Acid treated clay	Clarsil	200-300
Magnesia-silica gel	Florsil	300
Fuller's earth	Cecacite, Clarisil PSC-G	120-250
Diatomaceous	Chromosorb P	4

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TABLE 1-continued

	Sorbent	Trade Name	Surface Area, m/gm
5	earth	Chromosorb W Chromosorb G Chromosorb A	1 .5 2.7
	<u>NATURAL ZEOLITES</u>		
	Analcite		700-800 All
	Brewsterite		
10	Cancrinite		
	Chabazite		
	Edingtonite		
	Epistilbite		
	Erionite		
	Faujasite		
15	Gismondite		
	Gmelinite		
	Harmotome		
	Heulandite		
	Laumontite		
	Levynite		
20	Metascolecite		
	Metathomsonite		
	Mesolite		
	Mordenite		
	Natrolite		
	Phillipsite		
25	Scolecite		
	Staurite		
	Stilbite		
	Thomsonite		
	Zoisite		
	<u>ALUMINAS</u>		
30	Active Alumina	Alcoa F-1, Reynolds R-2101, Kaiser KA 201, Harshaw AL-0104T Alcoa F-6	90-400    200
	Co—C12 impregnated		
35	Catalytic alumina	Pechiney	300
	Activated bauxite	Florite	
	Chromatographic alumina	Alcoa F-20	225
	<u>CARBONS</u>		
40	Shell-based	Cochranex FCB Picatif T.A. Acticarbene NC Barnebey-Chaney AC Girdler 32E Acticarbene AC Darco KB Supersorbon W Carboraffin Brilonit Cochranex FCN-1 Picotif C.O. Picotif CM Darco granular Cochranex FCP-1 Pittsburgh BPL Barnebey-Cheney MN	800-1100 1000-1600 1200-1500 800-1100 800-900 750-1400 600-1200 1400 1000-1500 750-900 600-1000 800-1200 600-1200 500-1200 800-1000 1000-1400 110
	Wood based	Acticarbene Darco KB Supersorbon W Carboraffin Brilonit Cochranex FCN-1 Picotif C.O. Picotif CM Darco granular Cochranex FCP-1 Pittsburgh BPL Barnebey-Cheney MN	750-1400 600-1200 1400 1000-1500 750-900 600-1000 800-1200 600-1200 500-1200 800-1000 1000-1400 110
45		Acticarbene Darco BC Norit Supersorbon Acticarbene Columbia	850-1300 1300-1500 600-700 500-1600 1300-1400 700-900 800-1100
	Coal based		
50			
	Peat based		
55			
	Petroleum based		
60	ORGANIC MATERIALS		
	Crosslinked polystyrene	Chromosorb 101, 103	15-35
	Porous resin	Asmit 224	3
	Polystyrene (cross-linked)	Amberlite XAD-2 Amberlite XAD-4 Chromosorb 102 Duolite S-30 Amberlite XAD-7 Amberlite XAD-8	330 750 300-400 450 110

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TABLE 1-continued

Sorbent	Trade Name	Surface Area, m/gm
Cellulose	Whatman CC31	30000

The Stirling engine working gas volume 5 is pressurized with pure hydrogen which has been doped with carbon dioxide gas. The hydrogen is typically at a pressure of about 150 bar and may typically range over the course of the cycle between 135 and 165 bar. The carbon dioxide gas dopant is preferably in the range of 0.1 to 1.0%.

The sorbent, carbon dioxide adsorption charge, the volume of the cell, and the configuration of the porous window are selected such that the selected 0.1 to 1.0% concentration of carbon dioxide is maintained as the equilibrium partial pressure in the Stirling engine at its operating temperature and pressure. As some of the carbon dioxide gas reacts with the interior surfaces of the Stirling engine to form a hydrogen permeation barrier, additional carbon dioxide is released from the sorbent into the engine such that the partial pressure is maintained constant. If the hydrogen is doped with carbon dioxide before the diffusion cell is inserted and if the sorbent is fully saturated with carbon dioxide gas, a relatively small cell volume may be possible.

As the engine is operated, the molecules of carbon dioxide gas are slowly converted in the Stirling engine, particularly in the heater tubes, to water vapor molecules. Some of the water vapor molecules enter the cell interior 4. The selectivity of the molecular sieve sorbent for particular species is such that a water vapor molecule will displace an adsorbed carbon dioxide molecule and become adsorbed in its place. In this manner, excess water vapor from the Stirling engine is exchanged for additional carbon dioxide.

Optionally, additional activated adsorbent can be provided for adsorbing methane molecules which may form in the Stirling engine. For lower concentrations of carbon dioxide, some of the sorbent may be activated but have no carbon dioxide adsorbed thereon. This enables water vapor and methane to be adsorbed without displacing like numbers of carbon dioxide molecules.

As yet another option, the sorbent may be loaded with carbon monoxide dopant. Typically, larger volumes of sorbent are required to supply required concentrations of carbon monoxide. Because only a fraction of the adsorption sites of the sorbent are typically loaded with carbon monoxide, a large number of sites are available for the adsorption of water vapor and methane products.

As yet another option, water may be substituted for carbon dioxide as the adsorbed dopant. Water vapor is an effective dopant source of oxygen for metal oxide formation on the inner walls of the Stirling engine heater tubes. When water vapor is used as the dopant, no undesirable gaseous byproducts are formed. The cell volume can be relatively small as compared to a carbon monoxide source because no adsorbent sites need be reserved for chemical reaction byproducts.

In operation, the activated sorbent 1 is contained inside the enclosure 2. The Stirling engine working gas volume 5 is pressurized with pure hydrogen which has been doped with water vapor to a preselected dopant concentration, typically lower than 1000 ppm. The cell is typically positioned within the Stirling engine in such

a position that it is heated to the range of 200°–400° F. Increasing the temperature increases the partial pressure of the water vapor in the working gas and decreasing the temperature decreases the concentration of water vapor. The regeneration portion of the Stirling engine typically extends between the warmer and cooler portions of the engine. By interconnecting the cell in the appropriate position along the regenerator wall, the heating temperature of the diffusion cell can be selected. When the engine is shut down and cools, the diffusion cell also cools. At the lower temperatures, the sorbent increases its adsorption of water vapor, removing potentially corrosive water vapor and water condensation from the Stirling engine. At 70° F., the partial pressure of water vapor is typically in the range of 0.0003 psi.

The concentration of water vapor is selected to be below the saturation pressure of water at the working temperature and pressure of the Stirling engine. At a working temperature of 50° C. and a working pressure of 150 bar, a water vapor concentration of 822 ppm represents the saturation level. Accordingly, the sorbent is loaded and its temperature is maintained such that the equilibrium water vapor pressure in the cell volume 4 and the engine volume 5 is less than the saturation pressure in the coldest region of the engine, commonly the engine cooler.

With reference to FIG. 2, the diffusion cell may also be mounted exterior to the Stirling engine. The gas passing means further includes an extender tube 11 which provides a fluid passage between the working volume of the engine and the diffusion cell. A flow restrictor 12 and the relatively long narrow dimension of the extender tube 11 limit pressure gradient changes at the diffusion cell. This enables the diffusion cell to be connected with a portion of the working volume of the engine in which the pressure gradients vary by providing a relatively minimal pressure variation at the diffusion cell. The flow restrictor 12 may perform the flow limiting function rather than porous window 3. The porous window then functions merely as a screen to retain the sorbent in the cell and may be of a thinner and less restrictive construction.

Optionally, a heater 13 may be provided for controlling the temperature of the diffusion cell. The heater 13 may control the partial pressure of the selected dopant as described above. As yet another option, the diffusion cell may be charged with dopant after the interconnection with the engine. The heater is used to drive off any adsorbed molecules while the working volume of the Stirling engine is evacuated. After the sorbent has been activated, the dopant may be supplied through the Stirling engine, generally mixed with hydrogen gas.

With reference to FIG. 3, the dopant concentration in the working gas may be maintained uniformly by passing the working gas through the dopant cell. Such a cell is commonly denoted as a flow-through type cell. The flow-through type cell is installed in the working space of the engine such that the pressure gradients within the engine pump the working fluid through the cell. The enclosure 2 is configured as may be appropriate to use available non-working gas volume of the engine with a minimal, if any, increase in the overall engine volume. The gas passing means includes a first or inlet check valve 14 which opens at a relatively high pressure to fill manifold 15 with the working gas, e.g. at a pressure of 165 bar. When the working pressure drops to a relatively low pressure, e.g. about 135 bar, a second or



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outlet check valve 16 opens to drop an outlet manifold 17 toward the lower pressure. The pressure differential between manifolds 15 and 17 urges the working fluid through the flow-through cell.

The flow-through cell is constructed with two windows for flow restrictors. A first or inlet flow restrictor and filter 18 allows the working fluid to pass into the interior 4 of the cell. A second or outlet flow restrictor and filter 19 permits the working gas with any adsorbed dopant to pass from the flow-through cell. Preferably, the first and second filter and flow restrictors are constructed with a porous metal with about an 0.5 micron pore size. The thickness and frontal area of the flow restrictor and filters is selected to prevent sorbent particles from leaving the cell and to limit the rate at which hydrogen passes therethrough. Optionally, other flow restrictors, such as capillaries, parallel capillaries, porous metal, and the like may be utilized. The flow restrictors are selected to provide the minimum hydrogen flow through the sorbent which is necessary to maintain the desired dopant level in the engine volume. Because flow through the cell drains pressure waves from the engine, hence, costs energy, passing more than the minimum necessary flow is undesirable. Accordingly, the exact physical construction of the gas passing means, particularly the flow restrictors, will vary with engine size and configuration.

With reference to FIG. 4, a flow-through cell may also be mounted external to the engine. With the external mount, the gas passing means includes an inlet tube 20 and an outlet tube 21 which extend between the respective check valves and manifolds. The inlet and outlet check valves 14 and 16 are positioned close to the engine volume 5. In a free-piston Stirling engine, for example, the cell may be coupled to a gas spring volume, preferably the larger piston gas spring. Optionally, a heater 22 surrounds the cell and gas passing means to control the temperature thereof. Preferably, the heater draws waste heat from the combustor, preheater, or other high temperature components of the engine.

With reference to FIG. 5, the pressure gradient across the flow through cell may be created by an auxiliary pressure gradient creating means, such as a mechanical blower 23. The blower includes a fan and an auxiliary engine, such as an electrical motor. The continuous operation of the blower maintains an appropriate pressure gradient across the flow-through cell without relying on pressure gradients from the Stirling engine. Accordingly, check valves are no longer necessary. Rather, an inlet flow restrictor 24 and an outlet flow restrictor 25 provide flow resistance and isolate the cell from the pressure gradients of the engine.

With reference to FIGS. 6 and 7, the sorbent readily adsorbs gaseous molecules that are present in the air. As described above, the sorbent has a preference for certain molecules which displace other adsorbed molecules. Accordingly, if either the diffusion or flow-through cells are left exposed to the air, contaminants may be adsorbed on the sorbent. One solution described above is to charge the cells before they are connected with the Stirling engine. Such charging is conveniently done inside of a glove box, i.e. a closed containment with a controllable pressure and inert gas environment. To facilitate charging of the cells, an automatic cell enclosure means is provided.

In the embodiment of FIG. 6, the automatic enclosure means includes a base cover 26 which has one or more porous windows 27 which are sealed to the cover

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by weld 28 or the like. An expandable elastomeric sealing element 29 is connected by a fill tube 30 to the exterior of the closure cover 26. The expandable element 29 is bonded to the fill tube and the cover by an elastomer-to-metal adhesive 31.

Prior to connecting the cell to a Stirling engine, the cell is placed inside the glove box for charging with dopant. Screws 33 and cover 26 are removed and the cell is put inside the glove box. The box is then purged with inert gas until all air is removed from the box and open cell. After filling the cell with the activated sorbent, the closure cover 26 is sealed thereto with screws 33. A vacuum hose 34 is clamped with a clamp 35 to the fill tube 30. The vacuum hose extends through a feed-through 36 in the side wall of the glove box. A vacuum pump 37 is connected by a second vacuum tube 38 and a vacuum valve 39 with the first vacuum tube 34. A second vacuum valve 40 connects the vacuum tube 34 with a source 41 of inert gas. With the inert gas valve 40 closed and the vacuum valve 39 open, the vacuum pump is operated until the expandable element 29 collapses sufficiently that gas flows therepast to the interior of the cell. Vacuum valve 39 is closed and the appropriate dopant is injected into the glove box until the selected partial pressure of dopant has been reached. The selected partial pressure is maintained as the dopant is adsorbed on the sorbent 1, generally a period of five to thirty minutes. The valve 40 is then opened and compressed inert gas is fed into the collapsible element 29 until a pressure sufficient to seal the collapsible element against the walls is attained, generally about one to two atmospheres. The fill tube 30 is then permanently sealed closed, trapping the inert gas in the collapsible sealing element 29. The cell may then be removed from the glove box and attached to the Stirling engine.

If the cell is a flow-through cell, a like sealing means is provided at both ends. If the cell is a diffusion cell, only a single automatic sealing means need be provided. The pressure in the collapsible element is lower than the normal operating pressure of the Stirling engine. In this manner, once the Stirling engine is up to operating pressure, the collapsible element 29 collapses sufficiently to allow gas to flow therepast.

With reference to FIG. 7, the collapsible element 29 may be configured as an annular ring for selectively sealing and passing gas between the flow restrictors 27 and the interior of the cell. In the embodiment of FIG. 7, the fill tube 30 is sealed to the cover 26 by appropriate sealing means such as a weld 32. Alternately, other collapsible element arrangements may be provided.

With reference to FIG. 8, the collapsible element may be a metal bellows 42 rather than an elastomeric bladder. An O-ring 43 which is held in an O-ring groove 44 improves the gas tight seal between the expandable bellows and the cover 26. The interior of the bellows is again charged with an inert gas having sufficient pressure relative to atmospheric pressure to hold the bellows in the expanded state yet sufficiently low pressure relative to the operating pressure of a Stirling engine that the Stirling engine pressures compress the metal bellows allowing the exchange and flow of gas therepast. Various other loading and sealing arrangements may also be utilized, provided the completed cell contains sorbent which is free of contaminants and which is loaded with sufficient dopant to provide the selected dopant partial pressure in the engine.

Some Stirling engines achieve power control by varying the pressure of the hydrogen working gas. The

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engine is connected to a high pressure hydrogen reservoir which is maintained higher than the mean engine pressure. To provide a sudden increase in engine power, hydrogen or other working gas is quickly fed into the engine from the reservoir. To decrease the power supplied, the hydrogen is pumped from the engine back to the supply reservoir. This large increase and decrease in the pressure of the working gas is typically accompanied by large changes in the temperature of the stored working gas. This tends to cause water vapor gas to condense in the high pressure reservoir.

With reference to FIG. 9, water vapor is removed by trap cell 62 as the water vapor doped hydrogen flows from engine volume 5 to the high pressure reservoir. Water vapor is returned to the hydrogen as the gas is returned from the reservoir to engine volume 5. A sorbent 50 with an affinity for water vapor is located inside an enclosure 51 between porous windows 52 and 53. The sorbent 50 may be activated before attachment to the Stirling engine and the opening of control valve 54 or may be activated during engine charging. With particular reference to FIG. 10, the trap cell can be activated prior to engine operation by opening a vent valve 55 which connects the trap cell with a vent 56 while applying heat to the trap cell with heaters 57 and 58. The vent valve and the heaters are adjusted such that when valve 66 is opened, hydrogen flows from a high pressure hydrogen reservoir 59 through a heat exchanger 60, a check valve 61, the trap cell 62, the vent valve 55, and out of the vent 56. The sorbent is typically heated to the range of 200°-300° C. to desorb contaminating gases therefrom. After the cell activation has been completed, generally 5-30 minutes, vent valve 55 and reservoir valve 66 are closed and the heaters 57 and 58 turned off.

Once the trap cell 62 has been activated, the engine volume 5 may be purged in preparation for pressurizing and loading of either diffusion or flow-through cells with water vapor. The engine volume 5 is pressurized with hydrogen by opening the control valves 54 and 66 until hydrogen from the reservoir 59 has pressurized the engine through a flow restrictor 63 to the desired operating point. The flow restrictor 63 functions to isolate the hydrogen fill lines from pressure waves in the engine. After closing the control valves 54 and 66, water vapor is injected to load the cells, whether diffusion or flow-through type, associated with the engine.

To reduce the operating power level of the engine, valves 54 and 67 are opened and a compressor 64 pumps the working gas into the reservoir 59. More specifically, hydrogen doped with water vapor or other condensable dopant is pulled through the trap cell 62 and a check valve 65. The water vapor is adsorbed from the working gas such that only dry hydrogen is pumped into the reservoir 59. When more power is required, heater 57 is activated and control valves 54 and 66 are opened to provide higher pressure hydrogen or working gas to the engine volume 5. Dry hydrogen from the reservoir 59 is heated by the heat exchanger 60 before passing through the sorbent of the trap cell 62. In the trap cell, the hydrogen becomes doped with water vapor as it flows to the engine volume. Thereafter, the control valves 54 and 66 are closed.

The invention has been described with reference to the preferred and alternate embodiments. Obviously, modifications and alterations will occur to those of ordinary skill in the art upon reading and understanding the preceding detailed description. It is intended that

the invention be construed as including all such alterations and modifications insofar as they come within the scope of the appended claims or the equivalents thereof.

Having thus described the preferred embodiments, the invention is now claimed to be:

1. A method of maintaining a selected dopant gas concentration in the working gas of a Stirling engine, the method comprising:

adsorbing the selected dopant on an activated sorbent which has an affinity therefor;

connecting the dopant adsorbed sorbent in gaseous communication with the Stirling engine working gas such that a preselected equilibrium partial pressure is maintained between the dopant and working gases.

2. The method as set forth in claim 1 wherein the working gas is hydrogen and the dopant gas includes an oxide which reacts with surfaces of the Stirling engine to slow the rate of working gas permeation there-through.

3. The method as set forth in claim 2 in which the sorbent also has an affinity for water vapor and further including the steps of forming water vapor in the Stirling engine by interaction of the hydrogen and dopant gas oxides and adsorbing water vapor on the sorbent to maintain a preselected water vapor concentration in a working volume of the Stirling engine.

4. The method as set forth in claim 1 further including the step of adjusting the temperature of the sorbent to adjust the equilibrium partial pressure hence the dopant concentration.

5. The method as set forth in claim 1 wherein the working gas is hydrogen; the dopant gas is selected from the class consisting essentially of carbon monoxide, carbon dioxide, and water vapor; and the sorbent is selected from the class consisting essentially of a molecular sieve, activated alumina, activated carbon, and activated charcoal.

6. The method as set forth in claim 1 wherein the sorbent is selected from the class consisting essentially of: Aluminosilicates, Silica gel, Acid treated clay, Magnesia-silica gel, Fuller's earth, Diatomaceous earth, Analcite, Brewsterite, Cancrinite, Chabazite, Edingtonite, Epistilbite, Erionite, Faujasite, Gismondite, Gmelinite, Harmotome, Heulandite, Laumontite, Levynite, Metascolecite, Metathomsonite, Mesolite, Mordenite, Natrolite, Phillipsite, Scolecite, Staurite, Stilbite, Thomsonite, Active Alumina, Co-C12 impregnated, Catalytic alumina, Activated bauxite, Chromatographic alumina, Shell-based carbon, Wood based carbon, Coal based carbon, Peat based carbon, Petroleum based carbon, Crosslinked polystyrene, Porous resin, Polystyrene (cross linked), Phenolic Acrylic ester, and Cellulose.

7. The method as set forth in claim 6 wherein the working gas is hydrogen.

8. The method as set forth in claim 7 wherein the dopant gas interacts with surfaces of the Stirling engine to reduce the permeation of hydrogen therethrough.

9. The method as set forth in claim 8 wherein the dopant gas is selected from the class consisting essentially of inorganic and organic gases and vapors which (i) are adsorbed by the adsorbant and (ii) provide at least one of carbon, oxygen, and nitrogen molecules to react with the Stirling engine surfaces.

10. The method as set forth in claim 9 wherein the dopant gas is selected from the class consisting essen-

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tially of carbon monoxide, carbon dioxide, and water vapor.

11. In combination, a Stirling engine and a gas cell, the gas cell comprising:

- a hermetic enclosure which isolates an interior thereof from the atmosphere;
- an activated sorbent disposed in the hermetic enclosure; and,
- a gas passing means operatively connecting the hermetic enclosure interior and an interior of the Stirling engine such that gas flows therethrough.

12. The combination as set forth in claim 11 wherein a dopant gas is adsorbed on the sorbent such that dopant gas and a working gas of the Stirling engine flow through the gas passing means to establish a partial pressure therebetween.

13. The combination as set forth in claim 12 wherein the gas passing means includes a porous member through which the dopant and working gases diffuse.

14. The combination as set forth in claim 12 wherein the gas passing means includes:

- an inlet passage for passing at least the working gas from the Stirling engine to one side of the enclosure; and,
- an outlet passage for passing the working and dopant gases from another side of the enclosure to the Stirling engine such that the working gas is circulated through the sorbent.

15. The combination as set forth in claim 14 wherein the gas passing means further includes:

- a first check valve means for limiting gas flow in the inlet passage from the Stirling engine to the enclosure; and,
- a second check valve means for limiting gas flow in the outlet passage from the enclosure to the engine.

16. The combination as set forth in claim 14 wherein the gas passing means further includes:

- a first flow restrictor for limiting gas flow into the inlet passage from the Stirling engine; and,
- a second flow restrictor for restricting the flow of gas in the outlet passage from the enclosure to the engine.

17. The combination as set forth in claim 14 wherein the gas passing means further includes a mechanical

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means for increasing gaseous pressure, the mechanical gas pressure increasing means being disposed along one of the inlet and outlet passages to urge the working gas from the Stirling engine through the enclosure.

18. The combination as set forth in claim 12 wherein the enclosure includes at least one aperture for sealing interconnection with the gas passing means and an automatic closure means for sealing the aperture when the enclosure is separated from the gas passing means.

19. The combination as set forth in claim 18 wherein the automatic closure means includes a collapsible element which expands to close the aperture at atmospheric pressures and which collapses to allow gas to flow therepast at the operating temperatures and pressures of the Stirling engine.

20. A Stirling engine assembly which defines a working gas volume therein, the Stirling engine assembly comprising:

- a working gas reservoir for storing a working gas at a pressure greater than pressure of the working gas in the working volume of the Stirling engine;
- a trap cell operatively connected between an outlet of the reservoir and the Stirling engine working volume, the trap cell including an enclosure having porous windows at either end thereof and a sorbent with an affinity for water vapor therein, such that water vapor adsorbed on the sorbent diffuses into the hydrogen passing from the reservoir into the working engine;
- a compressor means for drawing working gas from the Stirling engine working volume, through the trap cell and pumping the working gas into the hydrogen reservoir, the sorbent in the trap cell at the reduced pressure caused by the compressor adsorbs water vapor from the working gas such that substantially dry working gas is pumped by the compressor into the reservoir, whereby the working gas is doped with water vapor by the tank cell as it passes into the Stirling engine and is dried by the trap cell as it is removed from the working engine for storage in the reservoir to prevent condensation of water vapor in the reservoir.

\* \* \* \* \*

# United States Patent [19]

Cornish

[11] Patent Number: **4,702,894**

[45] Date of Patent: **Oct. 27, 1987**

[54] **HYDROGEN SUPPLY UNIT**

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Cape Province, South Africa

[21] Appl. No.: **4,310**

[22] Filed: **Jan. 7, 1987**

**Related U.S. Application Data**

[63] Continuation of Ser. No. 790,361, Oct. 23, 1985, abandoned, which is a continuation of Ser. No. 332,803, Dec. 21, 1981, abandoned.

[30] **Foreign Application Priority Data**

Dec. 22, 1980 [ZA] South Africa ..... 80/8007

[51] Int. Cl.<sup>4</sup> ..... **B01J 19/08**

[52] U.S. Cl. .... **422/186.26; 48/61;**  
48/65; 123/DIG. 12; 422/186; 422/186.04

[58] Field of Search ..... 48/61, 65; 422/186,  
422/187, 199, 186.26, 186.04; 204/164, 58;  
123/3, DIG. 12; 423/657

[56] **References Cited**

**U.S. PATENT DOCUMENTS**

1,249,151	12/1917	McKee	422/186.26
3,224,952	12/1965	Via Loron	422/186.26
3,540,854	11/1970	Brooke et al.	423/657
3,648,668	3/1972	Pochero	123/DIG. 12
4,344,831	8/1982	Weber	123/DIG. 12

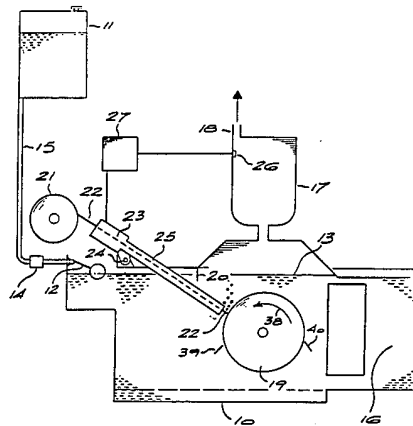
*Primary Examiner*—Peter Kratz

*Attorney, Agent, or Firm*—Cushman, Darby & Cushman

[57] **ABSTRACT**

Hydrogen is generated by heating a metal surface under water to a temperature at which the metal reacts with water to produce hydrogen. The hydrogen can then be used, for example, as a fuel for a motor vehicle engine or another type of engine. The heating can be done electrically by providing an electrical discharge, under water, between the metal surface and another surface. Water and the metal surface are consumed.

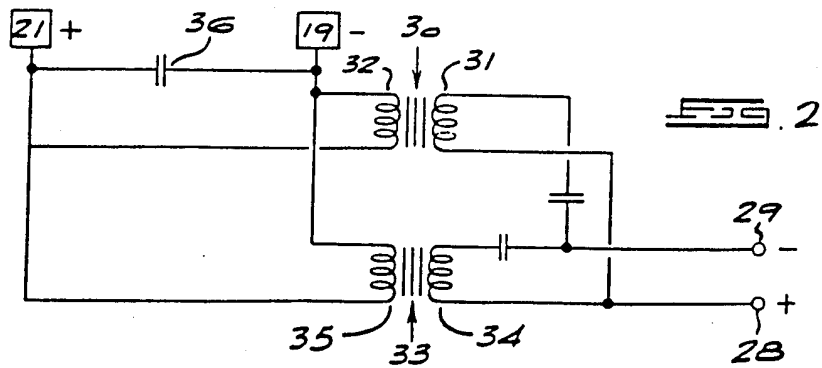
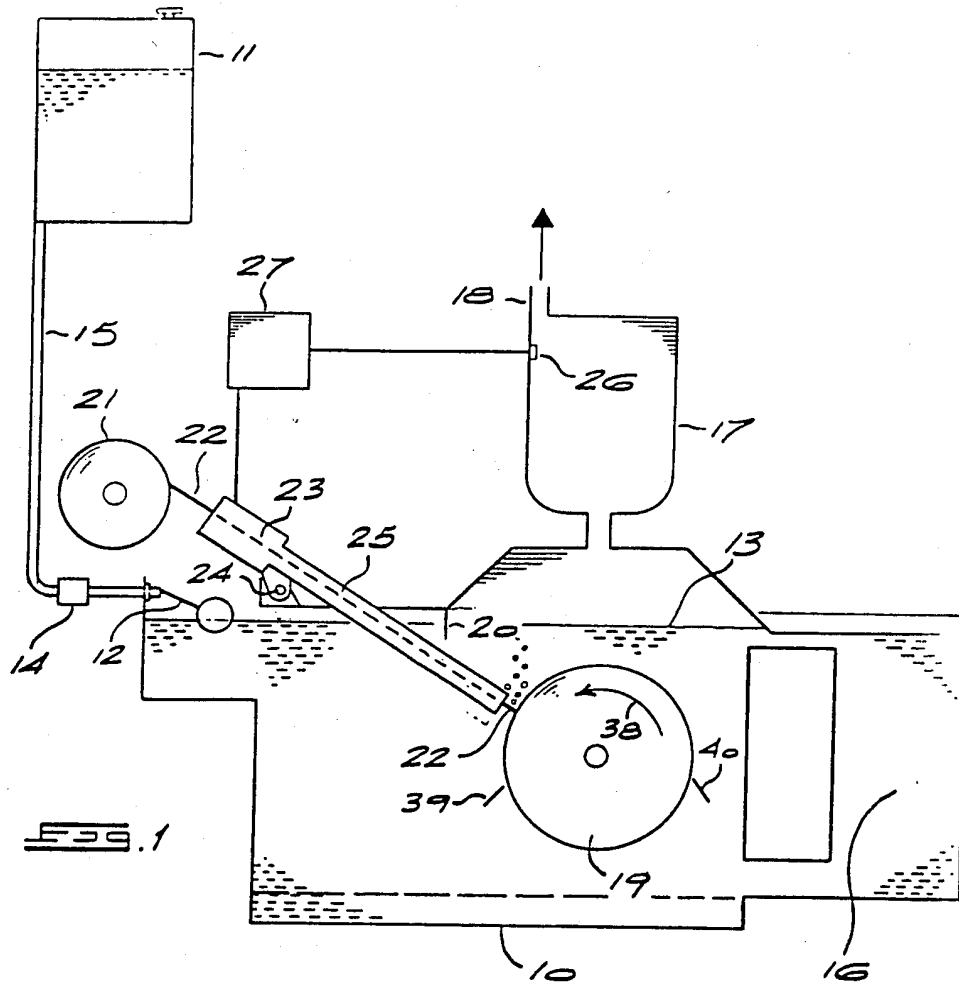
**7 Claims, 2 Drawing Figures**



U.S. Patent

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**HYDROGEN SUPPLY UNIT**

This is a continuation of application Ser. No. 790,361, filed Oct. 23, 1985, which was abandoned upon the filing thereof, which is a continuation of application Ser. No. 332,803, filed Dec. 21, 1981, now abandoned.

**BACKGROUND OF THE INVENTION**

This invention relates to hydrogen generation.

It has already been proposed to replace conventional fuels with hydrogen in the running of internal combustion engines. Conventional proposals are to produce hydrogen by the electrolysis of water and then to store the hydrogen in some form or another. No economically viable storage system for the highly explosive hydrogen gas has yet been evolved. Whatever system is evolved would involve fairly massive tanks of some kind or another and precautions to prevent explosions.

The present invention is based on the desire of the inventor to be able to provide hydrogen on demand from materials which are in themselves safe to handle.

**SUMMARY OF THE INVENTION**

According to the invention a method of generating hydrogen comprises the steps of exposing a fresh metal surface to water and heating the interface between the metal surface and the water at least to the lowest temperature at which the metal reacts with water to form a metal oxide and hydrogen, the metal being chosen from metals which are higher in the electromotive series than hydrogen and having stable and safe handling characteristics.

Preferably the metal surface is exposed and the interface heated by pressing an electrode of the relevant metal against a second electrode under water and applying a high voltage between the electrodes while, preferably, moving the electrode surfaces relatively to one another.

In other words in the preferred form of the invention hydrogen is formed by creating an underwater electrical discharge between two electrodes at least one of which is made of a metal as defined above.

The electrical discharge and the relative movement between the electrode surfaces ensure that fresh metal surfaces are exposed to the water while at the same time the discharge heats the interface between the electrodes and the water to the required temperature at which the metal reacts with water to form its oxide and to liberate hydrogen.

Also in the preferred form of the invention the metal is aluminum which has the advantage that it is in relatively abundant supply, relatively cheap, is formed with a protective oxide layer on its exposed surfaces and reacts with water at a relatively low temperature. Aluminum wire fed against a rotating aluminum drum has been found to give excellent results to provide hydrogen for powering small internal combustion engines.

A convenient way of securing the high voltage required is to employ the conventional distributor and coil arrangement which provides the sparking for an internal combustion engine. Two coils in parallel fed from a common distributor has been found to give excellent results. Other methods of generating high voltages from the battery or the drive shaft of an internal combustion engine may also be used.

The method of the invention lends itself in an excellent manner to supply hydrogen on demand. In this case

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hydrogen is fed to a small buffer store and as the pressure in the store exceeds a predetermined level, the electrodes are separated so that hydrogen generation is interrupted. As the pressure drops to a certain level the electrodes are again fed towards one another.

**BRIEF DESCRIPTION OF THE DRAWING**

The invention will now be further described, by way of example, with reference to the accompanying drawing, in which:

FIG. 1 is a schematic representation of apparatus for generating hydrogen, and suitable for powering a motor vehicle; and

FIG. 2 shows a portion of an appropriate electrical circuit.

**DESCRIPTION OF A PREFERRED EMBODIMENT**

In the illustrated embodiment there is a generating tank 10 fed with water from a reservoir tank 11 through a float valve 12 to keep the water level 13 in the tank 10 substantially constant. When the apparatus is used in a motor vehicle, the tank 11 can take the place of the conventional fuel tank of the vehicle with a pump 14 in the line 15 to pump more water into the tank 10 when the position of the float 12 indicates that this is required. Water is consumed as hydrogen is generated, and so the tank 11 has to be periodically refilled. The generating tank 10 is in communication with an air cooled heat exchanger 16, which may take the same form as a conventional motor car radiator.

The generating tank 10 is surmounted by a collecting vessel 17 from which hydrogen is drawn through a restricted orifice 18 of an internal combustion engine. Inside the tank 10 there is a drum 19 driven by any suitable means to rotate at a constant speed. The drum 19 is made of aluminum. A depending flange 20 provides a water seal to the top left hand corner of the tank 10, so that that corner is not in gas communication with the vessel 17.

A coil 21 of aluminum wire 22 is fed through a push-pull unit 23 of the kind used to feed welding wire to argon arc welding devices. The unit 23 is arranged to feed the wire against the surface of the drum 19 and to traverse the wire along the length of the drum on a bar 24. The wire passes along an insulating sleeve 25 which enters the tank 10 through a suitable wiper seal.

In the vessel 17 there is a pressure sensor 26 connected to a control unit 27. When the pressure sensor senses a pressure above a predetermined value, it signals the control unit 27 which in turn stops the unit 23 so that wire is no longer fed towards the drum 19. When the pressure drops again, feeding is resumed.

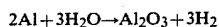
In use, the coil 21 is connected to the high tension side of two ignition coils or transformers 30 and 33. These transformers have primary windings 31 and 34 and secondary, high tension windings 32 and 35. A capacitor 36 is connected across the high tension connections. The terminals 28 and 29 are connected to a conventional vehicle battery.

At the point of contact between the end of the wire 22 and the drum 19 an electrical discharge takes place. As a result the adjacent metal surfaces are heated to a high temperature, the protective oxide film which naturally forms on exposed aluminium surfaces is disrupted, and the exposed aluminium surfaces react with the water. In fact the electrochemical situation at the interface

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is such that the wire 22 is consumed, with the following reaction taking place.



As a result, hydrogen bubbles from the contact point while the aluminum oxide collects as a white powder in the base of the tank 10. A grid 37 in the bottom of the tank allows the powder to pass through, and then keeps the powder substantially free from currents in the tank 10. The hydrogen passes through the vessel 17 and the orifice 18 to the carburettor of an internal combustion engine.

There may be a tendency for bubbles of hydrogen to adhere to the surface of the drum 19 which rotates in the direction indicated by the arrow 38. To prevent this happening, a wiper blade 39 can be located in the position shown in FIG. 1, so as to separate any adhering bubbles from the drum surface.

Alternatively, a wiper blade 40 may be arranged on the opposite side of the drum. In this case a small volume of hydrogen gas may collect beneath this blade and it may be possible to pivot the blade 40, thus releasing this pocket of hydrogen in order to facilitate start-up of an engine fueled by the hydrogen.

It may be possible to use salt water in the tank 10, rather than fresh water.

The drum 19 preferably rotates at a speed between 400 and 700 rpm, but the rotation may be as slow as 50 rpm.

During operation, the temperature of the water in the tank 10 may rise as high as 95° C., although it is likely that a unit mounted in a moving vehicle, for example, will be able to maintain the water at a lower temperature.

A unit substantially as shown in the drawings has been used to drive a 500 cc motor cycle engine. The wire 22 had a diameter of 1.6 mm and was of commercial purity (98% Al). The unit produced over 1000 cc of hydrogen a minute, with an aluminium wire consumption rate of 140 to 180 cm per minute. The rate of deposition of aluminium oxide was about 4 kilograms per 500 kilometers travelled.

Conventional modifications were made to the carburettor to enable the engine to run on a mixture of hydrogen and air.

The wire 22 carries a voltage of about 18000 volts with a current of about 1 amp.

The invention may equally be used to power stationary industrial engines, as well as motor vehicle engines.

I claim:

1. Apparatus for generating hydrogen comprising:

a tank for containing water;

a first metal element and a second metal element disposed in said tank;

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a metal surface of said first metal element being disposed adjacent to a metal surface of said second metal element with the metal substrates of both surfaces being in an electrical circuit to form respective positive and negative electrodes between which an electrical discharge may be made to take place;

means for moving said metal surface of said first metal element continuously toward said metal surface of said second metal element;

means for providing a current in said electrical circuit which includes said metal surfaces of sufficient intensity such that an electrical discharge between said positive and negative electrodes occurs causing the metal of at least one of said electrodes to react with water in the vicinity thereof resulting in the formation of a metal oxide and the generation of hydrogen; and

means for collecting the generated hydrogen.

2. Apparatus as claimed in claim 1, wherein the first metal element is aluminum.

3. Apparatus as claimed in claim 1, wherein the second metal surface is aluminum.

4. Apparatus as claimed in claim 1, wherein the tank is connected to a heat exchanger, so that water can circulate from the tank, through the heat exchanger, and back to the tank.

5. Apparatus for generating hydrogen comprising a tank containing water, a first metal surface and a second metal surface arranged in the tank, said first metal surface being connected to said second metal surface in an electrical circuit to form a positive and a negative electrode between which an electrical discharge may be made to take place, means for moving the first metal surface relative to the second metal surface, means for providing a current in the electrical circuit formed by the connection of the first and second metal surfaces such current being of sufficient intensity that when applied to the circuit, an electrical discharge between the electrodes will occur causing the electrodes to react with water in the vicinity thereof resulting in the generation of hydrogen and means for collecting the generated hydrogen, and wherein the first metal surface is a wire and the second metal surface is a drum, the drum being mounted for rotation and the wire being supported so that it approaches the cylindrical surface of the drum at an angle to a tangent to the drum surface.

6. Apparatus as claimed in claim 5, wherein the wire is supported by a device which continuously feeds the wire, as it is consumed, towards the drum surface.

7. Apparatus as claimed in claim 6, wherein means are provided for sensing the pressure of hydrogen gas in the chamber and for regulating the feed rate of the wire feeding device in accordance with the sensed pressure, to control the hydrogen output.

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**EUROPEAN PATENT APPLICATION**

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(51) Int. Cl.<sup>3</sup>: **C 01 B 3/08, F 02 B 43/00**

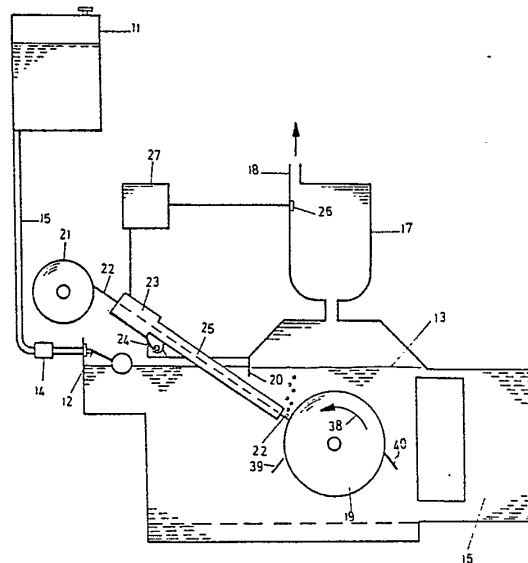
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(71) Applicant: Cornish, Francois Patrick, "Uitentuis",  
Steynsrus Road, Somerset West Cape Province (ZA)(43) Date of publication of application: 30.06.82  
Bulletin 82/26(72) Inventor: Cornish, Francois Patrick, "Uitentuis",  
Steynsrus Road, Somerset West Cape Province (ZA)(34) Designated Contracting States: AT BE CH DE FR GB IT  
LI NL SE(74) Representative: Raynor, John et al, W.H.Beck, Greener  
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(GB)

(54) Hydrogen supply unit.

(57) Hydrogen is generated by heating a metal surface (22) under water to a temperature at which the metal reacts with water to produce hydrogen. The hydrogen can then be used, for example, as a fuel for a motor vehicle engine or another type of engine. The heating can be done electrically by providing an electrical discharge, under water, between the metal surface and another surface. Water and the metal surface are consumed.

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BACKGROUND OF THE INVENTION

THIS invention relates to hydrogen generation.

It has already been proposed to replace conventional fuels with hydrogen in the running of internal combustion engines. Conventional proposals are to produce hydrogen by the electrolysis of water and then to store the hydrogen in some form or another. No economically viable storage system for the highly explosive hydrogen gas has yet been evolved. Whatever system is evolved would involve fairly massive tanks of some kind or another and precautions to prevent explosions.

The present invention is based on the desire of the inventor to be able to provide hydrogen on demand from materials which are in themselves safe to handle.

SUMMARY OF THE INVENTION

According to the invention a method of generating hydrogen comprises the steps of exposing a fresh metal surface to water and heating the interface between the metal surface and the water at least to the lowest temperature at which the metal reacts with water to form a metal oxide and hydrogen, the metal being chosen from metals which are higher in the electromotive series than hydrogen and having stable and safe handling characteristics.

Preferably the metal surface is exposed and the interface heated by pressing an electrode of the relevant metal against a second electrode

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under water and applying a high voltage between the electrodes while, preferably, moving the electrode surfaces relatively to one another.

5 In other words in the preferred form of the invention hydrogen is formed by creating an underwater electrical discharge between two electrodes at least one of which is made of a metal as defined above.

10 The electrical discharge and the relative movement between the electrode surfaces ensure that fresh metal surfaces are exposed to the water while at the same time the discharge heats the interface between the electrodes and the water to the required temperature at which the metal reacts with water to form its oxide and to liberate hydrogen.

15 Also in the preferred form of the invention the metal is aluminium which has the advantage that it is in relatively abundant supply, relatively cheap, is formed with a protective oxide layer on its exposed surfaces and reacts with water at a relatively low temperature. Aluminium wire fed against a rotating aluminium drum has been found to give excellent results to provide hydrogen for powering small internal combustion engines.

20 A convenient way of securing the high voltage required is to employ the conventional distributor and coil arrangement which provides the sparking for an internal combustion engine. Two coils in parallel fed from a common distributor has been found to give excellent results. Other methods of generating high voltages from the battery or the drive shaft  
25 of an internal combustion engine may also be used.

The method of the invention lends itself in an excellent manner to supply hydrogen on demand. In this case hydrogen is fed to a small buffer store and as the pressure in the store exceeds a predetermined level, the electrodes are separated so that hydrogen generation is

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interrupted. As the pressure drops to a certain level the electrodes are again fed towards one another.

#### BRIEF DESCRIPTION OF THE DRAWING

The invention will now be further described, by way of example, with reference to the accompanying drawing, in which:

- 5 Figure 1 is a schematic representation of apparatus for generating hydrogen, and suitable for powering a motor vehicle; and Figure 2 shows a portion of an appropriate electrical circuit.

#### DESCRIPTION OF A PREFERRED EMBODIMENT

- In the illustrated embodiment there is a generating tank 10 fed with water from a reservoir tank 11 through a float valve 12 to keep  
10 the water level 13 in the tank 10 substantially constant. When the apparatus is used in a motor vehicle, the tank 11 can take the place of the conventional fuel tank of the vehicle with a pump 14 in the line 15 to pump more water into the tank 10 when the position of the float 12 indicates that this is required.  
15 Water is consumed as hydrogen is generated, and so the tank 11 has to be periodically refilled. The generating tank 10 is in communication with an air cooled heat exchanger 16, which may take the same form as a conventional motor car radiator.

- The generating tank 10 is surmounted by a collecting vessel 17  
20 from which hydrogen is drawn through a restricted orifice 18 of an internal combustion engine. Inside the tank 10 there is a drum 19 driven by any suitable means to rotate at a constant speed. The drum 19 is made of aluminium. A depending flange 20 provides a water seal to the top left hand corner of the tank  
25 10, so that that corner is not in gas communication with the vessel 17.

A coil 21 of aluminium wire 22 is fed through a push-pull unit 23 of the kind used to feed welding wire to argon arc welding devices. The unit 23 is arranged to feed the wire against the surface

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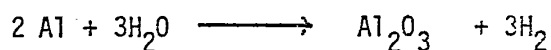
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of the drum 19 and to traverse the wire along the length of the drum on a bar 24. The wire passes along an insulating sleeve 25 which enters the tank 10 through a suitable wiper seal.

- 5 In the vessel 17 there is a pressure sensor 26 connected to a control unit 27. When the pressure sensor senses a pressure above a predetermined value, it signals the control unit 27 which in turn stops the unit 23 so that wire is no longer fed towards the drum 19. When the pressure drops again, feeding is resumed.

- 10 In use, the coil 21 is connected to the high tension side of two ignition coils or transformers 30 and 33. These transformers have primary windings 31 and 34 and secondary, high tension windings 32 and 35. A capacitor 36 is connected across the high tension connections. The terminals 28 and 29 are connected to a conventional vehicle battery.

- 15 At the point of contact between the end of the wire 22 and the drum 19 an electrical discharge takes place. As a result the adjacent metal surfaces are heated to a high temperature, the protective oxide film which naturally forms on exposed aluminium surfaces is disrupted, and the exposed aluminium surfaces react  
20 with the water. In fact the electrochemical situation at the interface is such that the wire 22 is consumed, with the following reaction taking place.



- As a result, hydrogen bubbles from the contact point while the aluminium oxide collects as a white powder in the base of the  
25 tank 10. A grid 37 in the bottom of the tank allows the powder to pass through, and then keeps the powder substantially free from currents in the tank 10. The hydrogen passes through the vessel 17 and the orifice 18 to the carburettor of an internal combustion engine.

- 30 There may be a tendency for bubbles of hydrogen to adhere to the surface of the drum 19 which rotates in the direction indicated by the arrow 38. To prevent this happening, a wiper blade 39

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can be located in the position shown in Figure 1, so as to separate any adhering bubbles from the drum surface.

Alternatively, a wiper blade 40 may be arranged on the opposite side of the drum. In this case a small volume of hydrogen gas may collect beneath this blade, and it may be possible to pivot the blade 40, thus releasing this pocket of hydrogen in order to facilitate start-up of an engine fueled by the hydrogen.

It may be possible to use salt water in the tank 10, rather than fresh water.

- 10 The drum 19 preferably rotates at a speed between 400 and 700 rpm, but the rotation may be as slow as 50 rpm.

During operation, the temperature of the water in the tank 10 may rise as high as 95°C, although it is likely that a unit mounted in a moving vehicle, for example, will be able to maintain the water at a lower temperature.

A unit substantially as shown in the drawings has been used to drive a 500cc motor cycle engine. The wire 22 had a diameter of 1.6 mm and was of commercial purity (98%Al). The unit produced over 1000 cc of hydrogen a minute, with an aluminium wire consumption rate of 140 to 180 cm per minute. The rate of deposition of aluminium oxide was about 4 kilograms per 500 kilometers travelled.

Conventional modifications were made to the carburettor to enable the engine to run on a mixture of hydrogen and air.

- 25 The wire 22 carries a voltage of about 18000 volts with a current of about 1 amp.

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The invention may equally be used to power stationary industrial engines, as well as motor vehicle engines.

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## CLAIMS

1.

Apparatus for generating hydrogen comprising a tank (10) for containing water, a metal surface (22) arranged in the tank, means for heating the surface at least to the lowest temperature at which the metal reacts with water to form a metal oxide and hydrogen, and a chamber (17) for collecting the generated hydrogen.

2.

Apparatus as claimed in Claim 1, wherein the metal surface (22) is aluminium.

3.

Apparatus as claim in Claim 1 or Claim 2, wherein the means for heating the surface is an electrical discharge between the surface (22) and another electrode (14).

4.

Apparatus as claimed in Claim 4, wherein a second metal surface (19) is arranged in the tank, and means are provided to move one surface (19) relative to the other, the two surfaces being connected in an electrical circuit (Figure 2) so that they form electrodes between which an electrical discharge can take place. —

5.

Apparatus as claimed in Claim 4, wherein the second metal surface is aluminium (19).

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6.

Apparatus as claimed in Claim 4 or Claim 5, wherein the first metal surface (22) is a wire and the second metal surface (19) is a drum, the drum being mounted for rotation and the wire being supported so that it approaches the cylindrical surface of the drum at an angle to a tangent to the drum surface.

7.

Apparatus as claimed in Claim 6, wherein the wire (22) is supported by a device (23) which continuously feeds the wire, as it is consumed, towards the drum surface (19).

8.

Apparatus as claimed in Claim 7, wherein means (26,27) are provided for sensing the pressure of hydrogen gas in the chamber (17) and for regulating the feed rate of the wire feeding device (23) in accordance with the sensed pressure, to control the hydrogen output.

9.

Apparatus as claimed in any preceding claim, wherein the tank (10) is connected to a heat exchanger (16), so that water can circulate from the tank, through the heat exchanger, and back to the tank.

10.

A method of generating hydrogen comprising the steps of exposing a fresh metal surface (22) to water and heating the interface between the metal surface and the water at least to the lowest temperature at which the metal reacts with water to form a metal oxide and hydrogen, the metal being chosen from metals which are higher in the electro-motive series than hydrogen and which have stable and safe handling characteristics.



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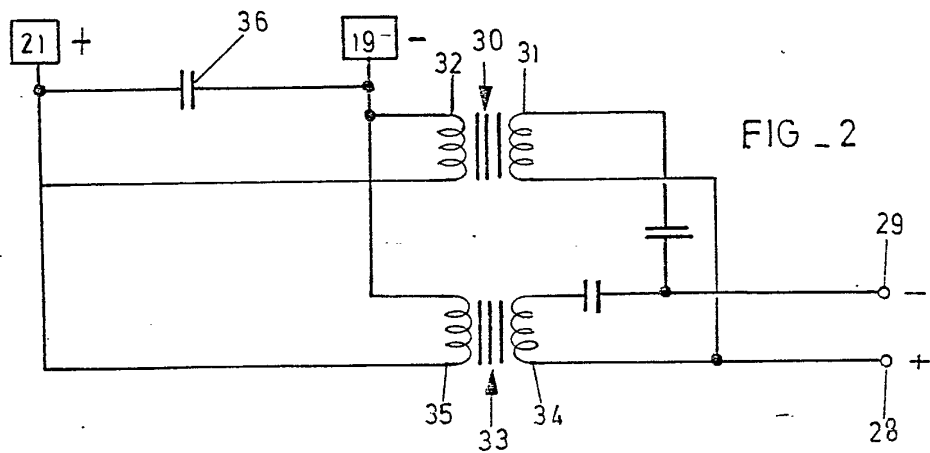
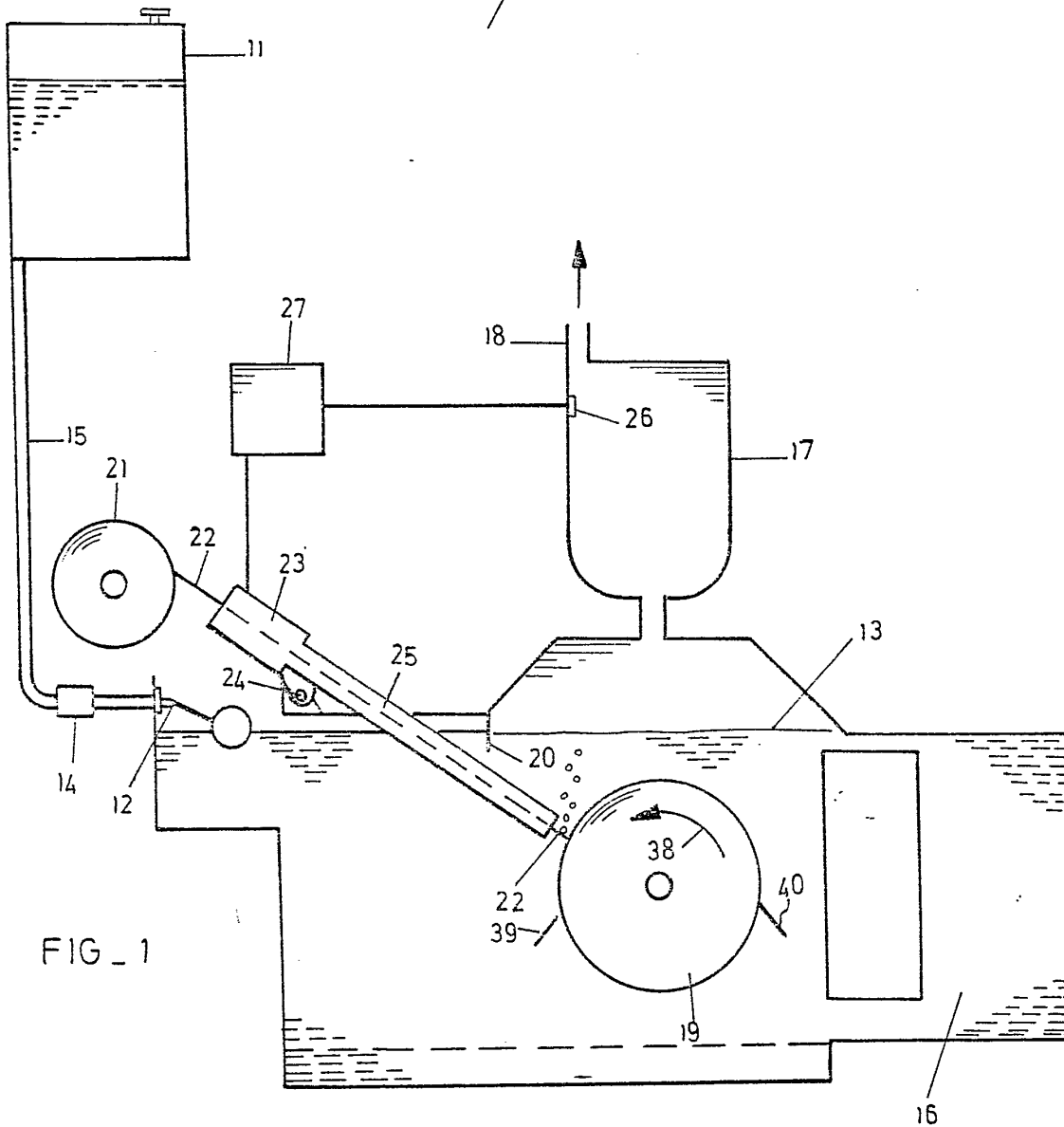
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11.

A method as claimed in Claim 10, wherein the metal (22) is aluminium, and a fresh metal surface is exposed and the interface heated by pressing an aluminium electrode (22) against a second electrode (19) under water and applying a high voltage between the electrodes.

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European Patent  
Office

# EUROPEAN SEARCH REPORT

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Application number

EP 81 30 6059.7

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	<u>US - A - 3 648 668</u> (F. PACHECO) * claim 1 * --	1	C 01 B 3/08 F 02 B 43/00
X	<u>DE - A1 - 2 360 568</u> (U. STUDENSKI) * complete document * ----	1,7, 10	TECHNICAL FIELDS SEARCHED (Int.Cl. 3)  B 60 K 15/00 C 01 B 3/00 F 02 B 43/00 F 02 M 21/00
			CATEGORY OF CITED DOCUMENTS  X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons  &: member of the same patent family, corresponding document
X	The present search report has been drawn up for all claims		
Place of search		Date of completion of the search	Examiner
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**EP 0 055 134 B1**

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Courier Press, Leamington Spa, England.

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**Description****Background of the Invention**

This invention relates to hydrogen generation.

It has already been proposed to replace conventional fuels with hydrogen in the running of internal combustion engines. Conventional proposals are to produce hydrogen by the electrolysis of water and then to store the hydrogen in some form or another. No economically viable storage system for the highly explosive hydrogen gas has yet been evolved. Whatever system is evolved would involve fairly massive tanks of some kind or another and precautions to prevent explosions.

The present invention is based on the desire of the inventor to be able to provide hydrogen on demand from materials which are in themselves safe to handle.

U.S. Patent No. 3648668 discloses a method for the production of hydrogen by the electrolysis of water using a magnesium electrode. In accordance with the present invention, there is provided a method and apparatus for generating hydrogen by reduction of water using a metal such as aluminium which does not require the complex control circuitry of the above U.S. Patent for controlling the electrolysis, but instead relies on the relative movement of two metal surfaces under the water surface and the formation of an electrical discharge between the two said metal surfaces.

Accordingly, this invention provides a method of generating hydrogen which method comprises the steps of urging a metal surface against another metal surface under water, moving the surfaces relative to one another, forming an electrical discharge between the metal surfaces, the metal of at least one of the surfaces being chosen from metals which are higher in the electromotive series than hydrogen and which have stable and safe handling characteristics.

Preferably, the metal surface is exposed and the interface heated by pressing an electrode of the relevant metal against a second electrode under water and applying a high voltage between the electrodes while moving the electrode surfaces relatively to one another.

The invention also provides apparatus for generating hydrogen comprising a tank for containing water, an aluminium surface arranged in the tank to be urged towards a metal surface movable relative to the aluminium surface, an electrical circuit connected between the surfaces to provide an electrical discharge between the surfaces, and a chamber for collecting the generated hydrogen.

The electrical discharge and the relative movement between the electrode surfaces ensure that fresh metal surfaces are exposed to the water while at the same time the discharge heats the interface between the electrodes and the water to the required temperature at which the metal reacts with water to form its oxide and to liberate hydrogen.

Also in the preferred form of the invention the metal is aluminium which has the advantage that it is in relatively abundant supply, relatively cheap, is formed with a protective oxide layer on its exposed surfaces and reacts with water at a relatively low temperature. Aluminium wire fed against a rotating aluminium drum has been found to give excellent results to provide hydrogen for powering small internal combustion engines.

A convenient way of securing the high voltage required is to employ the conventional distributor and coil arrangement which provides the sparking for an internal combustion engine. Two coils in parallel fed from a common distributor has been found to give excellent results. Other methods of generating high voltages from the battery or the drive shaft of an internal combustion engine may also be used.

The method of the invention lends itself in an excellent manner to supply hydrogen on demand. In this case hydrogen is fed to a small buffer store and as the pressure in the store exceeds a predetermined level, the electrodes are separated so that hydrogen generation is interrupted. As the pressure drops to a certain level the electrodes are again fed towards one another. The invention will now be further described, by way of example, with reference to the accompanying drawing, in which:

Figure 1 is a schematic representation of apparatus for generating hydrogen, and suitable for powering a motor vehicle; and

Figure 2 shows a portion of an appropriate electrical circuit.

In the illustrated embodiment there is a generating tank 10 fed with water from a reservoir tank 11 through a float valve 12 to keep the water level 13 in the tank 10 substantially constant. When the apparatus is used in a motor vehicle, the tank 11 can take the place of the conventional fuel tank of the vehicle with a pump 14 in the line 15 to pump more water into the tank 10 when the position of the float 12 indicates that this is required. Water is consumed as hydrogen is generated, and so the tank 11 has to be periodically refilled. The generating tank 10 is in communication with an air cooled heat exchanger 16, which may take the same form as a conventional motor car radiator. So that water can circulate from the tank, through the heat exchanger, and back to the tank.

The generating tank 10 is surmounted by a collecting vessel 17 from which hydrogen is drawn through a restricted orifice 18 of an internal combustion engine. Inside the tank 10 there is a drum 19 driven by any suitable means to rotate at a constant speed. The drum 19 is made of aluminium. A depending flange 20 provides a water seal to the top left hand corner of the tank 10, so that the corner is not in gas communication with the vessel 17. A coil 21 of aluminium wire 22 is fed through a push-pull unit 23 of the kind used to feed welding wire to argon arc welding devices. The unit 23 is arranged to feed the wire

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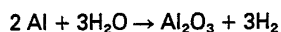
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continuously against the surface of the drum 19 at an angle to a tangent to the drum surface, and to traverse the wire along the length of the drum on a bar 24. The wire passes along an insulating sleeve 25 which enters the tank 10 through a suitable wiper seal.

In the vessel 17 there is a pressure sensor 26 connected to a control unit 27. When the pressure sensor senses a pressure above a predetermined value, it signals the control unit 27 which in turn stops the unit 23 so that wire is no longer fed towards the drum 19. When the pressure drops again, feeding is resumed.

In use, the coil 21 is connected to the high tension side of two ignition coils or transformers 30 and 33. These transformers have primary windings 31 and 34 and secondary, high tension windings 32 and 35. A capacitor 36 is connected across the high tension connections. The terminals 28 and 29 are connected to a conventional vehicle battery.

At the point of contact between the end of the wire 22 and the drum 19 an electrical discharge takes place. As a result the adjacent metal surfaces are heated to a high temperature, the protective oxide film which naturally forms on exposed aluminium surfaces is disrupted, and the exposed aluminium surfaces react with the water. In fact the electrochemical situation at the interface is such that the wire 22 is consumed, with the following reaction taking place.



As a result, hydrogen bubbles from the contact point while the aluminium oxide collects as a white powder in the base of the tank 10. A grid in the bottom of the tank allows the powder to pass through, and then keeps the powder substantially free from currents in the tank 10. The hydrogen passes through the vessel 17 and the orifice 18 to the carburettor of an internal combustion engine.

There may be a tendency for bubbles of hydrogen to adhere to the surface of the drum 19 which rotates in the direction indicated by the arrow 38. To prevent this happening, a wiper blade 39 can be located in the position shown in Figure 1, so as to separate any adhering bubbles from the drum surface.

Alternatively, a wiper blade 40 may be arranged on the opposite side of the drum. In this case a small volume of hydrogen gas may collect beneath this blade, and it may be possible to pivot the blade 40, thus releasing this pocket of hydrogen in order to facilitate start-up of an engine fueled by the hydrogen.

It may be possible to use salt water in the tank 10, rather than fresh water.

The drum 19 preferably rotates at a speed between 400 and 700 rpm, but the rotation may be as slow as 50 rpm.

During operation, the temperature of the water in the tank 10 may rise as high as 95°C, although it

is likely that a unit mounted in a moving vehicle, for example, will be able to maintain the water at a lower temperature.

A unit substantially as shown in the drawings has been used to drive a 500cc motor cycle engine. The wire 22 had a diameter of 1,6 mm and was of commercial purity (98% Aluminium). The unit produced over 1000 cc of hydrogen a minute, with an aluminium wire consumption rate of 140 to 180 cm per minute. The rate of deposition of aluminium oxide was about 4 kilograms per 500 kilometers travelled.

Conventional modifications were made to the carburettor to enable the engine to run on a mixture of hydrogen and air.

The wire 22 carries a voltage of about 18000 volts with a current of about 1 amp.

The invention may equally be used to power stationary industrial engines, as well as motor vehicle engines.

### Claims

1. Apparatus for generating hydrogen comprising a tank (10) for containing water, an aluminium surface (22) arranged in the tank (10) to be urged towards a metal surface (19) movable relative to the aluminium surface (22), an electrical circuit connected between the surfaces (19, 22) to provide an electrical discharge between the surfaces (19, 22), and a chamber (17) for collecting the generated hydrogen.

2. Apparatus as claimed in Claim 1, wherein the metal surface (19) is aluminium.

3. Apparatus as claimed in Claim 1 or Claim 2, wherein the aluminium surface (22) is a wire and the metal surface (19) is a drum, the drum being mounted for rotation and means (23) being provided for supporting the wire so that it approaches the cylindrical surface of the drum at an angle to a tangent to the drum surface.

4. Apparatus as claimed in Claim 3, wherein the support means (23) is arranged to continuously feed the wire, as it is consumed, towards the drum surface (19).

5. Apparatus as claimed in Claim 4, wherein means (26, 27) are provided for sensing the pressure of hydrogen gas in the chamber (17) and for regulating the feed rate of the wire feeding device (23) in accordance with the sensed pressure, to control the hydrogen output.

6. Apparatus as claimed in any preceding claim, wherein the tank (10) is connected to a heat exchanger (16), so that water can circulate from the tank, through the heat exchanger, and back to the tank.

7. A method of generating hydrogen comprising the steps of urging a metal surface against another metal surface under water, moving the surfaces relative to one another, forming an electrical discharge between the metal surfaces, the metal of at least one of the surfaces being chosen from metals which are higher in the electromotive series than hydrogen and which have stable and safe handling characteristics.

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8. A method according to Claim 7, in which at least one of the metal surfaces is formed of aluminium.

### Revendications

1. Appareil pour la production d'hydrogène, comprenant une cuve à eau (10), une surface d'aluminium (22) disposée dans la cuve (10) et sollicitée à se mouvoir vers une surface métallique (19) mobile par rapport à la surface d'aluminium (22), un circuit électrique branché entre les surfaces (19, 22) pour produire une décharge électrique entre les surfaces (19, 22), et une chambre (17) de réception de l'hydrogène produit.

2. Appareil suivant la revendication 1, dans lequel la surface métallique (19) est une surface d'aluminium.

3. Appareil suivant la revendication 1 ou la revendication 2, dans lequel la surface d'aluminium (22) est la surface d'un fil tandis que la surface métallique (19) est la surface d'un tambour, ledit tambour étant monté mobile en rotation et un moyen (23) étant prévu pour supporter ledit fil de manière à ce qu'il soit amené à la surface cylindrique du tambour sous un angle à une tangente de la surface de ce dernier.

4. Appareil suivant la revendication 3, caractérisé en ce que le moyen de support (23) est conçu pour avancer le fil en continu, au fur et à mesure de sa consommation, vers la surface (19) du tambour.

5. Appareil suivant la revendication 4, dans lequel des moyens (26, 27) sont prévus pour détecter la pression du gaz hydrogène dans la chambre (17) et pour réguler l'avance du fil par le dispositif d'avance (23) selon la pression détectée, afin de réguler la production d'hydrogène.

6. Appareil suivant l'une quelconque des revendications précédentes, dans lequel la cuve (10) communique avec un échangeur de chaleur (16) de manière à ce que l'eau circule de la cuve vers l'échangeur de chaleur et retourne ensuite dans la cuve.

7. Procédé de production d'hydrogène, comprenant les étapes consistant à appliquer une surface métallique contre une autre surface métallique au sein d'eau, à déplacer lesdites surfaces l'une par rapport à l'autre, à provoquer une décharge électrique entre lesdites surfaces métalliques le métal d'au moins l'une desdites surfaces étant choisi parmi les métaux qui sont supérieurs à l'hydrogène dans l'échelle des forces électromotrices et qui présentent un caractère de stabilité et de sécurité lors de leurs manipulations.

8. Procédé suivant la revendication 7, dans

lequel au moins l'une desdites surfaces métalliques est constituée d'aluminium.

### Patentansprüche

1. Vorrichtung zur Herstellung von Wasserstoff umfassend einen Tank (10) zum Enthalten von Wasser, eine Aluminiumoberfläche (22), die im Tank (10) angeordnet ist, um auf eine Metalloberfläche (19) hin gedrückt zu werden, die in bezug auf die Aluminiumfläche (22) bewegbar ist, einen elektrischen Schaltkreis, der zwischen den Oberflächen (19, 22) angeschlossen ist, um eine elektrische Entladung zwischen den Oberflächen (19, 22) zu bewirken, und eine Kammer (17) zum Sammeln des hergestellten Wasserstoffs.

2. Vorrichtung nach Anspruch 1, worin die Metalloberfläche (19) Aluminium ist.

3. Vorrichtung nach Anspruch 1 oder 2, worin die Aluminiumoberfläche (22) ein Draht und die Metalloberfläche (19) eine Trommel ist, die Trommel zur Drehung montiert ist und eine Einrichtung (23) zur Abstützung des Drahtes auf solche Weise vorgesehen ist, daß er sich der zylindrischen Oberfläche der Trommel in einem Winkel zu einer Tangente zur Trommeloberfläche annähert.

4. Vorrichtung nach Anspruch 3, worin die Abstützeinrichtung (23) so angeordnet ist, daß sie den Draht, während er verbraucht wird, kontinuierlich auf die Trommeloberfläche (19) hin zuführt.

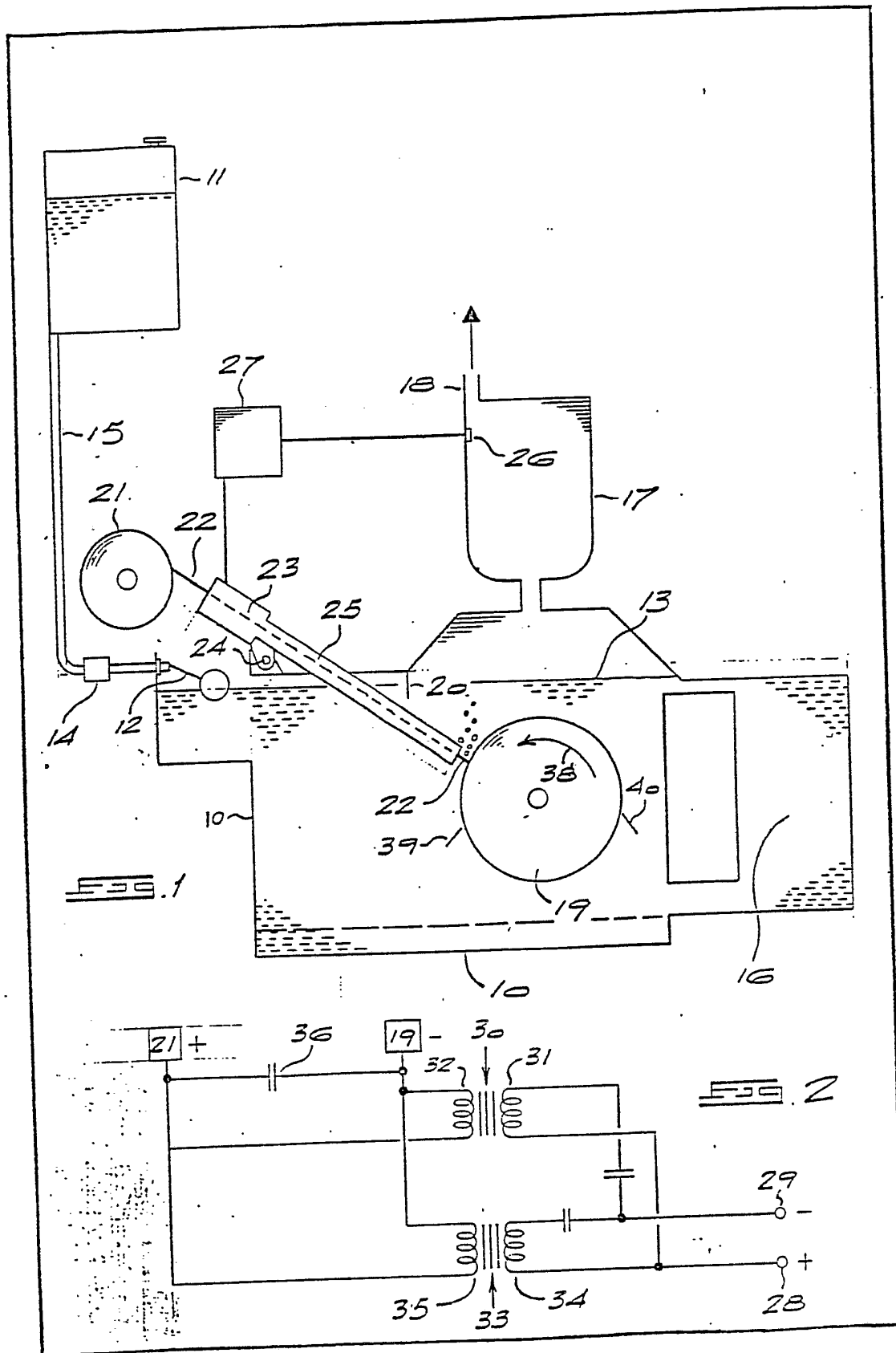
5. Vorrichtung nach Anspruch 4, worin Einrichtungen (26, 27) zum Abfühlen des Druckes des Wasserstoffgases in der Kammer (17) und zur Steuerung der Zufuhrgeschwindigkeit der Drahtzufuhrvorrichtung (23) entsprechend dem erfüllten Druck vorgesehen sind, um den Wasserstoffausstoß zu regeln.

6. Vorrichtung nach einem der vorhergehenden Ansprüche, worin der Tank (10) mit einem Wärmetauscher (16) verbunden ist, so daß Wasser vom Tank zum Wärmetauscher und wieder zurück in den Tank zirkulieren kann.

7. Ein Verfahren zur Herstellung von Wasserstoff umfassend die Schritte des Drückens einer Metalloberfläche gegen eine andere Metalloberfläche unter Wasser, Bewegens der Oberflächen in bezug aufeinander, Herstellens einer elektrischen Entladung zwischen den Metalloberflächen, wobei das Metall wenigstens einer der Oberflächen aus Metallen ausgewählt wird, die höher in der elektrochemischen Reihe (elektromotorischen Spannungsreihe) stehen als Wasserstoff und betriebssichere Handhabungsmerkmale aufweisen.

8. Ein Verfahren nach Anspruch 7, in welchem wenigstens eine der Metalloberflächen aus Aluminium ausgebildet ist.

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N° 1300



A.D. 1896

Date of Application, 18th Jan., 1896

Complete Specification Left, 18th Nov., 1896—Accepted, 18th Jan., 1897

## PROVISIONAL SPECIFICATION.

**A Process and Furnace Installation for Continuous Process of Production of a Non-exploding Mechanical Admixture of Oxygen and Hydrogen.**

I, Dr. CHARLES POLONY of Vienna VI/2 Mittelgasse 6, Austria, Engineer, do hereby declare the nature of this invention to be as follows :—

The present invention concerns the production of a compound of oxygen and hydrogen which being produced by the decomposition of steam at a continually high temperature, without the aid of pipes, either straight or spiral, cannot explode. As in this process the decomposition of steam is not, as hitherto, due to an oxidation, either of a metal or otherwise, and as there are no chemical agencies that co-operate in the decomposition, to my knowledge, or that will engage one or the other of the constituent elements of water, as is the case with metallic pipes, both of the constituent elements of water are obtained, in my process of decomposition, as a mechanical admixture, at a high temperature, without any risk of explosion. This admixture is maintained in the furnace, or in some other locality, as long as the requisite conditions for its existence are offered, which is the case within the furnace installation. These conditions are—(seeing that water, assumed at 18 units of the atoms, requires 68,400 caloric units in order to be decomposed into its elements) :—the temperature just stated, a non-diffusive casing (metal, fire-clay, etc. are diffusive) and the friction arising by motion in chambers placed in tiers above, or parallel side by side with each other within the furnace. If the said temperature goes down, the gases having been brought to the highest degree of expansion, the formation of water will ensue, without an explosion, after the “*status-nascendi*” temperature. The cause for this differing behaviour of the gas compound obtained in this way, as compared with explosive oxy-hydrogen, is simply due to the different mode of production of the two compounds and the consequences thereof.

While explosive oxyhydrogen can be kept, as such, in unchanged condition, at a normal temperature, in closed vessels, my compound cannot be either produced or kept as such in the same way.

While in the case of explosive oxyhydrogen this effect characterising the mixture is produced by the sudden expansion of the gas atoms—in conjunction with the surrounding strata of air—by a “combination exciter,” my gas mixture, at the time of its formation as well as subsequently, is in that stage of expansion and temperature which, in the case of a combination of the constituents of oxyhydrogen to form water, does not occur until the very moment of combination; hence my gas compounds can never explode, neither during their production nor at the time of their recombination to form water.

It appears from this fact :

(a.) That explosive oxyhydrogen is produced in another way than the gas compound here in question, as in the former each constituent element of water is obtained quite separately from the other and the two are, afterwards only, mixed at a low temperature,—hence its material difference from the latter;

(b.) That explosive oxyhydrogen as such can be kept in an unchanged condition for a long time, which would not be possible in the case of my gas compounds

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except by separation, and subsequent recombination, of the constituents of the mixture, which object is not intended.

Consequently the gas compound here in question is essentially different from explosive oxyhydrogen; while the latter is absolutely useless for my purposes the former has eminent advantages for chemical wholesale industry.

According to the invention, the steam is overheated in a furnace suitable for obtaining maximum temperatures, in an enclosed chamber surrounded by heated (impermeable) fireproof brick walls, in which process the steam, owing to the absorption of a high degree of temperature, combined with friction and pressure, is transformed into the desired admixture of hydrogen and oxygen. As such it is passed on into a "treatment chamber" built into the centre of the furnace where it is immediately employed and made to act upon the substances introduced therein; in this immediate application, which is arranged so as to go on "*pari passu*" with the continuous process of production, the caloric energy contained in the gas mixture may be advantageously utilised. The material used for building these channels or chambers is chromic iron ore, which not only resists, to an extraordinary degree the high temperature, but is also impermeable. Any air incidentally entering with the steam will not in any way influence the process of decomposition.

Dated this 18th day of January 1896.

J. E. EVANS-JACKSON & Co.,  
Agents for the Applicant.

## COMPLETE SPECIFICATION.

**A Process and Furnace Installation for Continuous Process of Production of a Non-exploding Mechanical Admixture of Oxygen and Hydrogen.**

I, Dr. CHARLES POLONY of Mitteltgasse 6, Vienna VI/2, Austria, Engineer, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention concerns the production of a mixture of oxygen and hydrogen which, being produced by the decomposition of steam or aqueous vapor at a constantly high temperature, without the aid of pipes, either straight or spiral, cannot explode. As in this process the decomposition of water or steam is not, as hitherto, due to an oxidation, either of a metal or otherwise, since, as far as known, there are no chemical agencies that co-operate in the decomposition, or that will engage one or the other of the constituent elements of water, (as is the case if employing systems of metallic pipes, or an electric current, and the like) both of the constituent elements of water are obtained, in my process of decomposition, in mechanical admixture, at a high temperature, without any risk of explosion. This admixture is maintained in the furnace, or in some other receptacle, as long as the requisite conditions for its existence are offered. These conditions are,—seeing that water on being heated, in the furnace here described to a temperature of 2912 Fahr. will be completely decomposed into its constituent elements,—the temperature just stated, an impermeable casing (metal and fire-clay are permeable) and the friction caused by motion along channels, superposed in tiers, or arranged parallel and side by side to each other, within the furnace. Should the heat fall off below the "*status nascendi*" temperature, water will be formed, but without an explosion, which is altogether precluded by the fact that the gases had already been previously brought to their maximum of expansion. The cause of

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this differing behaviour of the gas mixture obtained in this way, as compared with explosive oxyhydrogen, is simply due to the different mode of production of the two mixtures and the consequences thereof.

While explosive oxyhydrogen produced on any system hitherto known can be kept, as such, in unchanged condition in closed vessels, at a normal temperature, my gas mixture cannot be either produced or stored as such in the same way.

While in the case of explosive oxyhydrogen the detonating effect characterising the mixture is produced by the sudden expansion of the gas atoms when combining with air from the surrounding strata of the atmosphere owing to the influence of any "combination exciter" (*i.e.* any agent which will promote recombination of the dissociated gases) my gas mixture, at the time of its formation as well as subsequently, is in that state of expansion and temperature which, in the case of the explosive oxyhydrogen mixture, does not supervene until the very moment of the combination of its constituents to form water; hence my gas compounds can never explode,—neither during their production, nor at the time of their recombination to form water, in consequence of a decrease of temperature.

It appears from this fact :—

(a.) That explosive oxyhydrogen is produced in another way than the gas mixture here in question, as in the former each of the two constituent elements of water is obtained quite separately from the other and it is not until afterwards that the one is admixed to the other, at a low temperature; hence the material difference between this and the gas mixture prepared by me, and the different behaviour of the latter at high temperatures.

(b.) That explosive oxyhydrogen, as such, can be kept in an unchanged condition for a long time, which would not be possible in the case of my gas compounds except by separating the two constituent gases and subsequently readmixing them, whereby (and not until then) ordinary explosive oxyhydrogen would be formed, which object is not intended.

Consequently, the gas mixture here in question is essentially different from explosive oxyhydrogen. While the latter is absolutely useless for the applications which I have in view, the former has eminent advantages for purposes of chemical wholesale industry.

According to my invention, steam or aqueous vapour or water spray or the like is overheated in a furnace suitable for obtaining maximum temperatures, in enclosed channels, formed and surrounded by heated impermeable fire-proof brick walls, in which process the steam, under the influence of a high degree of heat absorbed by it, combined with friction and pressure, is gradually transformed into the desired mixture of hydrogen and oxygen. As such it is passed on into a "treatment chamber" built into the centre of the furnace, where it is immediately utilised, being made to act, direct, upon substances or materials introduced therein; in this immediate application, which is arranged so as to go on "*pari passu*" with the continuous process of production, the caloric energy contained in the gas mixture may at the same time be utilised to advantage. The material used for building these channels or chambers is chromic iron ore, or so-called "chromate of iron" which not only resists elevated temperatures to an extraordinary degree, but is also impermeable at high temperatures. Any air incidentally entering with the steam will not in any way influence the process of decomposition.

In the accompanying drawings I have shown, by way of illustration, but without binding myself to this or any other definite form of furnace, an installation suitable for the carrying out of the process, in which :—

Fig. 1 is a horizontal section in the line 1—1, Fig. 3 and 5.

Fig. 2 is a horizontal section in the line 11—11, Fig. 3 and 5, above 1—1

Fig. 3 is a vertical section through the diametrical axis A—B, Fig. 1.

Fig. 4 a vertical section through the diametrical axis C—D, Fig. 1.

Fig. 5 is a vertical section, executed half way only, in the line Q—Q, Fig. 1.

Fig. 6 a similar partial vertical section in the line Q—P, Fig. 1.

Fig. 7 a corresponding partial section in the line Q—R.

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The furnace is divided, in the line of a diametrical axis C D, by a wall going right through from side to side, and only interrupted by the central chamber E, so that two independent halves of the furnace are obtained, available for alternate use. In the base of the furnace, on the near side of the transversal axis A B, there is the combustion chamber or hearth F, and on the further side of the axis A B the tunnel Z which serves for carrying off or removing the products obtained.

Five concentric semi-circular channels each, marked *b, a, b, c, d*, are arranged in tiers at various heights of the furnace and, by means of connecting passages leading from one tier to the other, form a series of channels or flues ascending or descending (as the case may be) in zig-zag fashion. The channels *b b* are heating passages and have one wall each in common with the intervening separate and independent channel *a*, which leads to chamber E, and in which the decomposition of the steam is effected. The supply of air required to maintain combustion is introduced from above at *c*<sup>1</sup> (Fig. 7), passing thence, through the channels *c*, in which it is preliminarily treated, to the mixing chamber P (Fig. 5) where it is mixed with the combustion gases.

In the combustion chamber F (Fig. 5) coal is placed in closely-packed layers on the grate R, where it undergoes an incomplete combustion because little air is supplied to it. The gases thus developed are first passed into the mixing or igniting chamber P, and thence, after being brought into contact with the highly heated air current issuing from the channels *c*, into the semi-circular passages *b*, in the lowermost tier, shown in plan view in Fig. 1. The combustion gases will ascend through vertical passages into the superposed tiers and will then pass, as indicated in Fig. 6, through the uppermost connecting channels *b*<sup>1</sup> *b*<sup>1</sup> into the downward channels or annular chambers *d* which serve to carry off the products of combustion into the chimney flue. During their passage through the channels *b* the gases formed in the combustion chamber and burnt to carbonic acid in the mixing or igniting chamber will transfer their heat to the channels *a* and *c* as well as the chamber E.

As already observed, cold air from outside enters the channels *c* through the suction aperture *c*<sup>1</sup> (Fig. 7) (but pure oxygen might just as well be admitted), which air (or oxygen) will pass downward from tier to tier and, while moving in an opposite direction to the heating or combustion gases contained in *b* will be heated before reaching the mixing chamber P. Between the passages for the heating gases *b, b*, but separated therefrom, are the channels *a*, in which the current of steam, introduced through the steam pipe *v* (Fig. 7), (and which is gradually converted into a gas mixture) moves in an opposite direction to that of the fire gases. During the downward passage of the steam current, within the channels *a*, it is decomposed, partly in the central tier, and more completely in the lower tier, to an extent of at least 95 % and in consequence of the pressure generated, the existing friction against the impervious walls, and the high existing temperature, it will enter the central chamber E of the furnace, through connecting channels *a*<sup>1</sup> *a*<sup>2</sup>, in the form of a mechanical mixture of gases composed of two parts of hydrogen and one part of oxygen. The direction of the gas current is indicated in the ground plans by arrows, feathered arrows indicating the course of the heating gases, and arrows without feathers marking the air or oxygen supply channels, while the course of the mixture of hydrogen and oxygen is indicated by arrows with forked ends. The two halves of the furnace installation, at either side of the central axis C D, Fig. 1 and 2, are two independently acting sets of furnace apparatus, which have only the combustion chamber or hearth F, the mixing or igniting chamber P and the central chamber E in common.

As regards the material used for the construction of the furnace, I have already pointed to chromic iron ore as a suitable material because it is impermeable at any temperature, and will perfectly resist the required high degree of heat; which properties may be said to have hitherto been proved to be possessed, at the elevated temperatures here in question, by this material only.

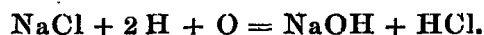
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One of the requisite conditions for the generation of the abovementioned mixture of oxygen and hydrogen, besides high temperature and the pressure arising of its own accord in the channel *a*, is the friction caused by the rough walls of the channel, so that, as a matter of fact, a non-explosive mixture of hydrogen and oxygen is formed in the channel, which mixture will keep its condition unchanged for any length of time if the conditions of its existence, indicated in the early part of this specification, *viz.*: heat and friction, are maintained. The ordinary fire-proof materials commonly used, will become porous and permeable at high temperatures, as is also the case with metals; hence all these substances are completely useless for the purposes of the present invention. The chamber *E* arranged in the centre of the furnace structure, is the reduction or oxidation chamber, and serves to receive the chemicals, gases, or solid substances to be subjected to the influence of free oxygen and hydrogen, and which are introduced at *O*.

The remaining residues are carried off through the pipe *S*, underneath a perforated plate *X*, which is moveable on hinges, to a place rendered accessible through the "tunnel" *Z*, underneath the chamber *E*, while, laterally above, a pipe *g* is fitted to the shaft as a discharge for the volatile products resulting from the process. The mixture of hydrogen and oxygen thus formed is intended to remain in a state of mechanical admixture within the furnace, or rather within the chamber *E*, until it has fulfilled its purpose in the latter, that is to say until it has been used for some process, or until the constituents of the mixture are used independently of each other. A suitable "separator," or medium of separation of the two gases contained in the furnace in mechanical admixture, is constituted for instance, by a thin partition of fire-brick material, platinum in thin sheets, an electric spark, or other means. An electric spark, for instance, will effect the separation of the gas mixture referred to, from each other, in such a simple and rapid way as to require but an exceedingly small quantity of electricity in order to separate large volumes of the said gas-mixture quickly, and with next to no expense. An equally successful separation of the two gases is effected by a layer of fire-brick material, the separation in this case being effected thanks to the different gravity and density of the two gases.

As an example of how industrial processes may be carried out in the chamber *E* under the conditions described, and with the aid of the gas-mixture produced, I may mention the following as one of such as cannot be carried out with equal success by any other method or while using other simple gases.

If the chamber *E* be charged with  $\text{NaCl}$ , the chloride of sodium, in the presence of free hydrogen ( $\text{H}^2$ ) and free oxygen ( $\text{O}$ ), would be decomposed owing to the high temperature, into volatile chlorine and  $\text{Na}$ ; in the "*status nascendi*," the chlorine would combine with  $\text{H}$  to form  $\text{HCl}$  and the  $\text{Na}$  would in the first place combine with the existing  $\text{O}$ , and then with the remainder of  $\text{H}$ , to form caustic soda, according to the following formula:—



If the chamber *E* or some other chamber which has assumed a lower temperature than *E*, is fed with a continuous supply of  $\text{SO}_2$ , and this is brought into contact with the mixture of hydrogen and oxygen or else with oxygen alone, there would be formed, out of the sulphurous acid  $\text{SO}_2$ ,—(not in chamber *E* itself, but in a chamber with a correspondingly lower temperature, or shortly before the condensation of the gases,)  $2\text{H} + 2\text{O} + \text{SO}_2 = \text{SO}_4\text{H}_2$  that is to say hydrated sulphuric acid, or in the second instance, when oxygen only is admitted, anhydrous sulphuric acid ( $\text{SO}_3$ ) which on admission of atmospheric air is most readily converted into  $\text{SO}_4\text{H}_2$ .

A modification of the aforesaid furnace, differing in some respects from the arrangement shown in Figs. 1 to 7, is shown in the annexed drawings Figs. 8 and 9, and more fully described hereinafter because, though working with the same materials, namely, water and coal, it yields different products. These products

*Polony's Process and Furnace Installation, &c.*

would be, during the first phase of the process—on first lighting the furnace—(a) hydrogen and carbonic acid; secondly (b) hydrogen and oxygen, and thirdly, (c) carbonic oxide, hydrogen and water.

Fig. 8. shows a part of the furnace and heating arrangement in sections corresponding to those shown in Fig. 5.

Fig. 9, similarly shows sections corresponding to those in Fig. 6.

Firstly. If the grate R. of the combustion chamber or hearth in Fig. 8, from which grate atmospheric air can be excluded by closing a register U, is charged with coal in thick layers, the coal on being ignited will at first undergo but an imperfect combustion because it does not receive a sufficient supply of air; the gases thus developed first pass into the mixing or igniting chamber P. where they are brought into contact and mixed with a current of air issuing from the channel C (and which at first is not very warm but gradually becomes hotter and hotter), and are consequently ignited. The burning gases next pass into the semi-circular channels *b* in the lowermost tier, shown in plan in Fig. 1. and thence through vertical connecting passages or flues into the next higher tier *b*, and from this, as shown in Fig. 9. through the connecting passage *b*<sup>1</sup> *b*<sup>1</sup> into the downward passages or annular chambers *d* which carry off the products of combustion into the chimney-flue W. Fig. 9. whence they are exhausted or passed into the chimney.

Hence the mode of setting the furnace to work, is as follows:—The furnace having attained a sufficient temperature in consequence of this initial heating, the aperture *c*<sup>1</sup> which supplies air to channel C. (Fig. 7) is closed, and immediately before doing so, steam is introduced into the furnace from a boiler through the steam pipe *v* Fig. 7. At the same time the register U. is closed in order to prevent any access of atmospheric air to the grate. Coal is introduced as required through the orifice S, which can be shut off by means of a sliding cover D, which is held in position by slide-bars or bolts. In order to prevent any access of air to the combustion chamber through this opening, the cover D. is shut again after the introduction of fresh fuel, whereupon the valve D<sup>1</sup> is opened and the coal contained in the feed-chamber S. is permitted to descend into the grate R, after which the valve D<sup>1</sup> is reclosed. As the current of steam introduced through pipe *v* descends along the channels *a* it is decomposed, to some part, even in the central tier, and more completely in the lowermost tier of channels, to an extent of at least 95 %, thanks to the friction against the impermeable walls of the channel and the existing high temperature, coupled with the pressure arising in the course of decomposition, and passes in the form of a gas compound consisting of two parts of hydrogen and one of oxygen, in mechanical admixture, through the connecting passages *a*<sup>1</sup> *a*<sup>2</sup> in Fig. 4. and Fig. 8. into a central chamber E. of the furnace Figs. 8 and 9.

The direction of the current of gases is indicated in the plans by arrows,—feathered arrows indicating the course taken by the combustion gases, and arrows without feathers the course of the air or oxygen supply, while arrows with forked ends indicate the course of the mixture of oxygen and hydrogen.

The chamber E. consists of a cylinder of chromate of iron material. Within this cylinder E. is a second cylinder made of firebrick material *d* *d*, Figs. 8 and 9.

This chamber E. communicates as described, with the channels *a* by means of the connecting apertures *a*<sup>1</sup> *a*<sup>2</sup>, see Figs. 1, 8 and 9. Through these apertures *a*<sup>1</sup> *a*<sup>2</sup> the compound of oxygen and hydrogen (now present in mechanical admixture) enter chamber E. from which hydrogen will filter or diffuse through the firebrick cylinder into the space in the interior of the latter, while the oxygen remains in chamber E. and passes thence through pipe O. Fig. 8. either upwards into a reservoir or gas-holder bell, or downwards, partly through the channel leading to Y. into the igniting chamber P. and partly through the same channel and X. underneath the grate R. The purpose of pipe O. is to conduct the oxygen (which, as it does not percolate through the firebrick cylinder, will accumulate in E. to the combustion chamber in order to support combustion, whenever it is

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thought expedient to use oxygen alone for this purpose. In this case valve C<sup>1</sup> (Fig. 7) is closed, in order to prevent all access of air there.

5 In this mode of working the products of combustion are exhausted by suitable apparatus at A (Fig. 9), from the channel *d* which can be shut off lower down, and in view of the great amount of heat which they still contain, are utilised for converting water into steam, and are then passed into a reservoir (gas-holder) whence they are conducted for the purpose of compression, to a compression pump, these products being, in fact, carbonic acid. The hydrogen accumulated within the firebrick cylinder is likewise conducted, in a continuous current, into a gas-  
10 holder, from which it is drawn, as required, through J. Fig. 8. The final results of this process, are carbonic acid on the one hand, and hydrogen on the other hand, with a high degree of heat.

Secondly. When sufficient hydrogen has accumulated in the gas-holder in which it is collected, the furnace installation here described by way of illustration, may  
15 be heated by its means, in conjunction with either atmospheric air or oxygen, instead of burning coal. In this case no charge of coal is placed on the grate R. (Fig. 8) which is shut off against the atmospheric air outside at D. S. If now, at the same time, instead of air, a current of hydrogen, from the hydrogen gas-holder is introduced into the igniting chamber P. through the air-supply orifice *c*<sup>1</sup> (Fig. 7)  
20 and channel C. it could be ignited there, being supplied with the oxygen or air required for its combustion through pipe O (Fig. 8) and Y, while X would remain shut off. In burning the hydrogen with air the register U. (Fig. 8) would have to be opened. The product of combustion would be water in the form of steam which, after giving off a great part of its heat in the channel *a*, would pass from  
25 this through the channels *b. b.* to *d*, whence it would be exhausted by suitable apparatus at A. or discharged through W. into the chimney (see Fig. 9).

This method of heating is inexpensive, while steam introduced into the furnace at *v* (Fig. 7) is decomposed quite as efficiently as if the furnace is heated with coal.

30 The final results of this process are hydrogen and oxygen, with a high degree of heat obtained without any consumption of coal.

The hydrogen, in this case, is abstracted at J. (Fig. 8) while the oxygen is exhausted by suitable apparatus at H. (Fig. 9). The two constituent elements of water are each stored in a separate gas-holder, because if they are brought into  
35 contact again after their separation their nature will be identical with that of the explosive compound known as oxyhydrogen.

Thirdly. If, according to local requirements, the heat generated by the combustion or oxidation of hydrogen is to be utilised in the furnace described for the production of ordinary coal-gas for heating and lighting purposes, the furnace is  
40 first heated up in the manner described, whereupon (or if the furnace is already hot) the process continues as follows:—

The two constituent elements of water are gained as described, in the furnace shown in Figs. 8 and 9 and are conveyed to their respective gas-holders. Thereupon, with a view to the further operation, the grate R. is charged with coal; all access  
45 of atmospheric air from outside is then cut off at *c*<sup>1</sup> (Fig. 7) and steam is admitted into the hot furnace at *v* (Fig. 7) whereupon all access of atmospheric air is also cut off at D and U (Fig. 8), the supply of oxygen required for maintaining the combustion of the coal on grate R. is then admitted, from the oxygen gas-holder, through pipe O, and introduced, highly heated, at X. (Fig. 8), while the discharge  
50 orifice at *y* is closed. The product thus obtained from the combustion of the coal, as it receives an insufficient supply of oxygen would be carbonic oxide, with hydrogen as a secondary product and a high degree of heat. If instead of oxygen only, the mechanical mixture of hydrogen and oxygen were admitted into the furnace, the products obtained would be carbonic oxide, hydrogen, and water (in  
55 the form of steam). The latter would be eliminated, by condensation, in the cooling process subsequently undergone by the coal-gas.

In this way, quite a variety of combinations may be obtained; the above

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*Polony's Process and Furnace Installation, &c.*

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mentioned examples are merely intended to illustrate the lucrative nature of this process of producing hydrogen and oxygen and its advantageous application for chemical or technical purposes.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is :— 5

1. Process for unintermittent production of a non-explosive mechanical mixture of oxygen and hydrogen,—which two elements, if desired, may also be obtained separate from each other by this process,—characterised by steam (or aqueous vapour or spray) being conducted through the channels or chamber of a furnace 10 built of impermeable and highly refractory material, such as chromate of iron, and strongly heated from outside, to a central chamber (which may be utilised as a reduction or oxidation chamber for various chemical operations), and in the course of this passage, under the influence of the high temperature, the pressure generated, and the friction against the walls of the channels or chambers, undergoing a 15 decomposition into hydrogen and oxygen in mechanical admixture; this mixture being retained in the furnace or in the aforesaid chamber, while maintaining the temperature, until its constituents are utilised for some chemical process, or until they are separated by electricity or some other means, as aforesaid.

2. For the execution of the process claimed under 1, a furnace installation, in 20 which the central (reduction or oxidation) chamber E. is surrounded by a series of concentric channels or chambers (*b, a, b, c, d,*) ascending or descending, respectively, in tiers, or grouped parallel or otherwise, and among which the channels *b, b,* are heating channels or flues, in which the products of combustion, after being previously mixed with a current, preliminarily heated in the channels *c,* of air or oxygen, and 25 ignited in consequence, are conducted upwards or in a parallel direction, along the walls of the channel *a* in which a current of steam, gradually converted into the aforesaid mixture of gases, moves in an opposite direction to that of the heating gases, which latter subsequently pass downwards along the outside channels *d,* and according to the requirements of the case, are either discharged into the 30 chimney or extracted by exhaustors and collected in suitable receptacles.

3. The modified form of the furnace necessitated by a different kind of fuel employed, in conjunction with the subsequent application, as fully described or exemplified above, the arrangement of the furnace installation generally to be 35 subject to such modifications and additions as may, as a matter of course, be necessitated by the nature of the fuel employed, and with a view to the subsequent applications of the constituent elements of water.

Dated this 17th day of November 1896;

J. E. EVANS-JACKSON & Co.,  
Agents for the Applicant. 40

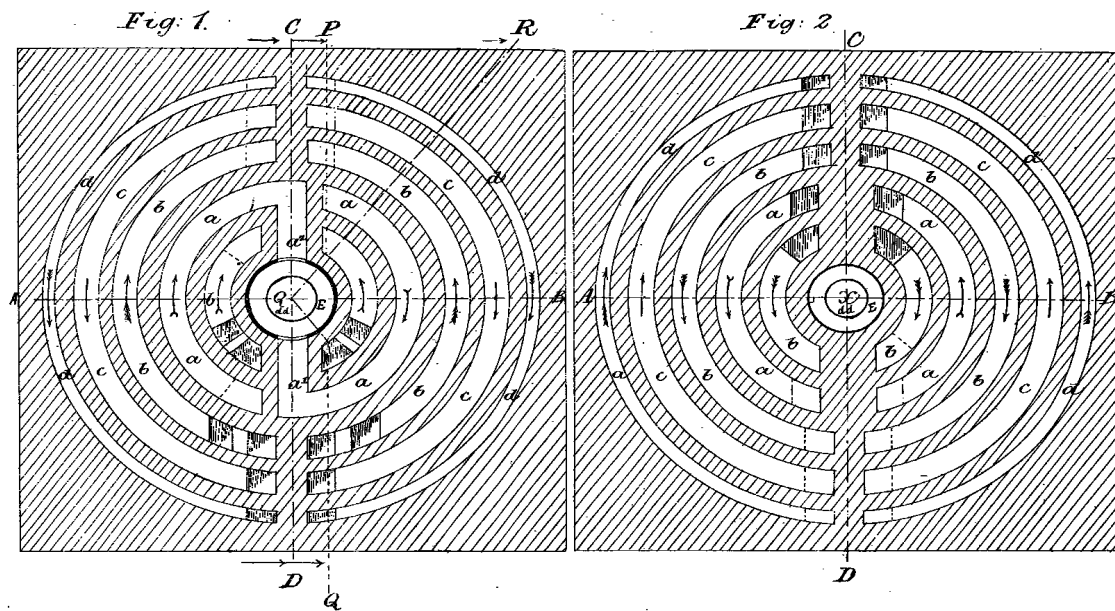
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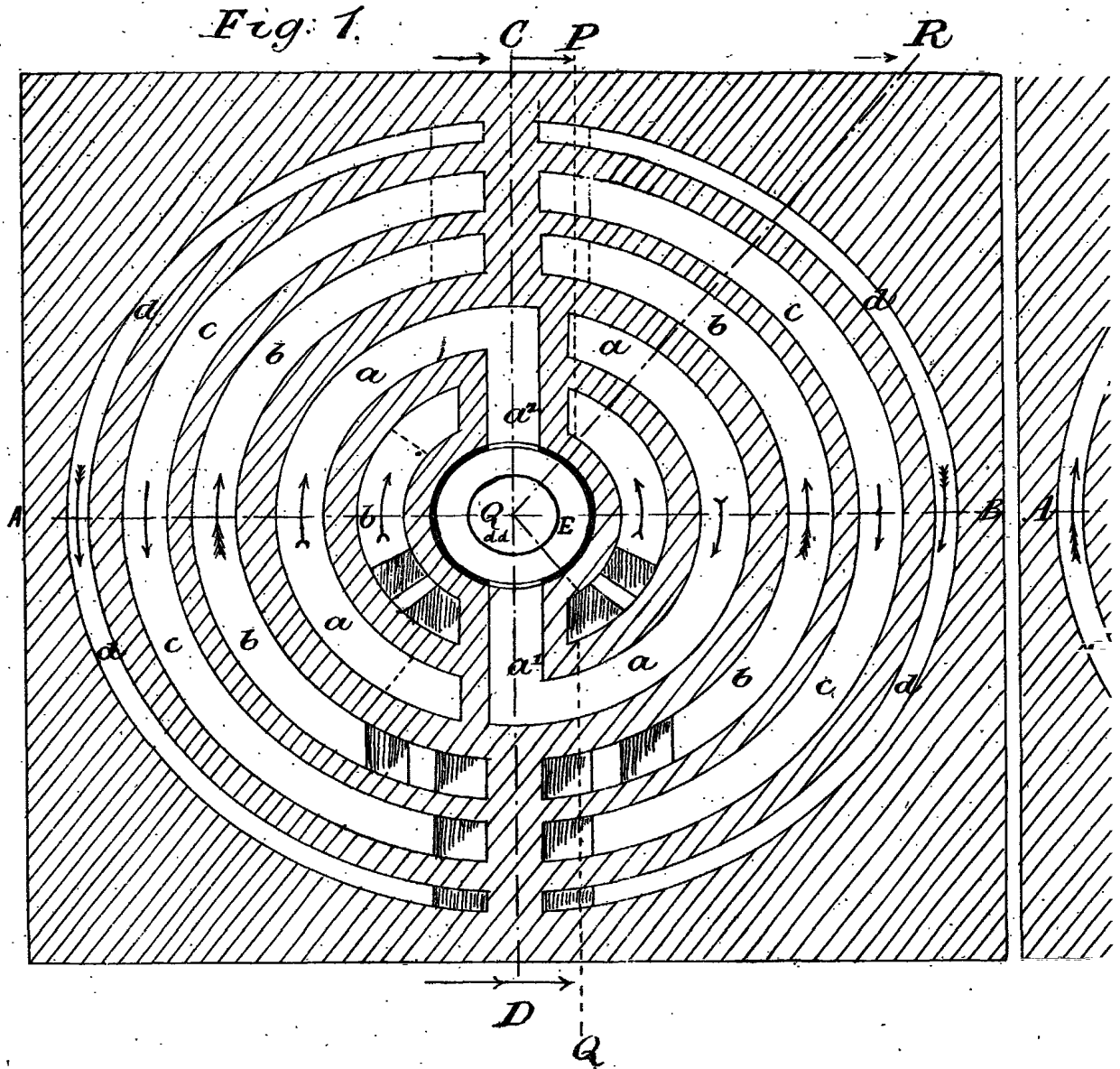
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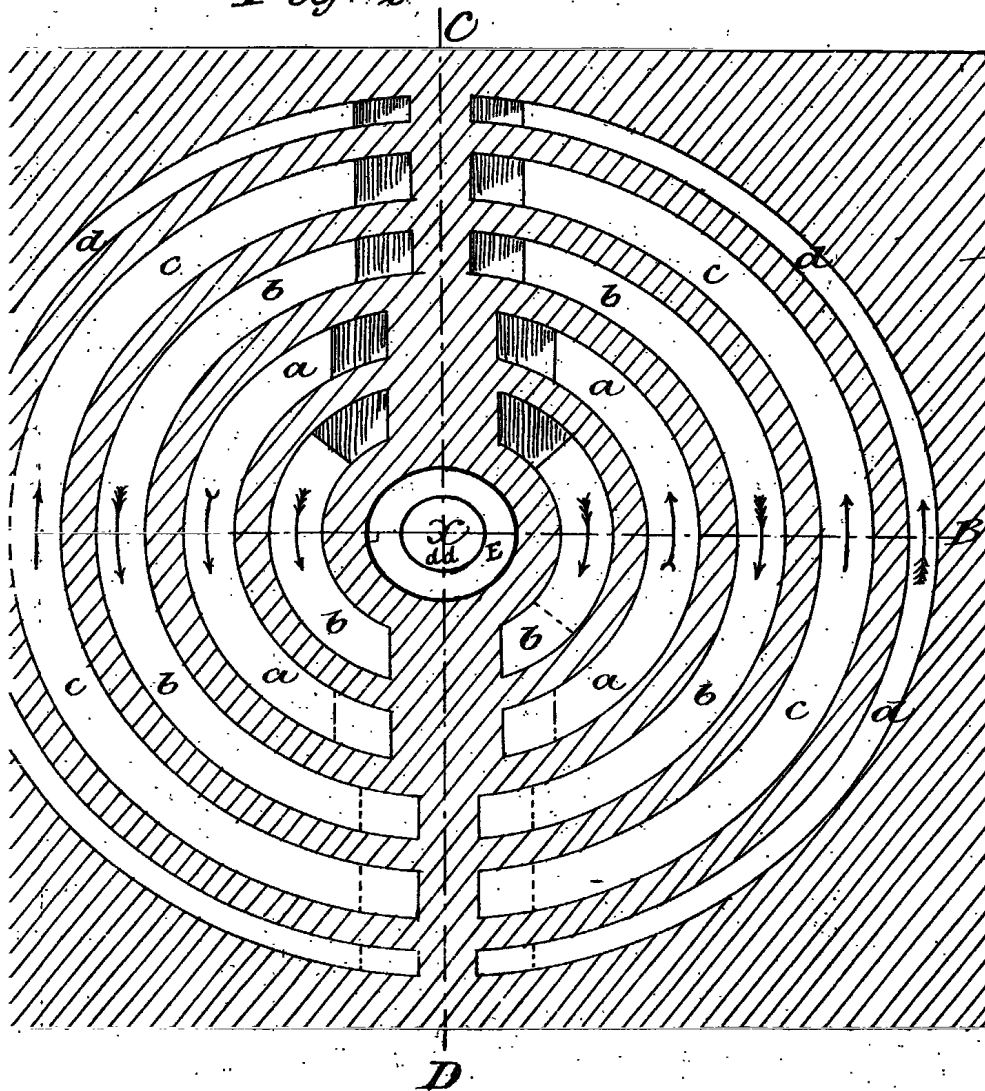
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Fig. 2.



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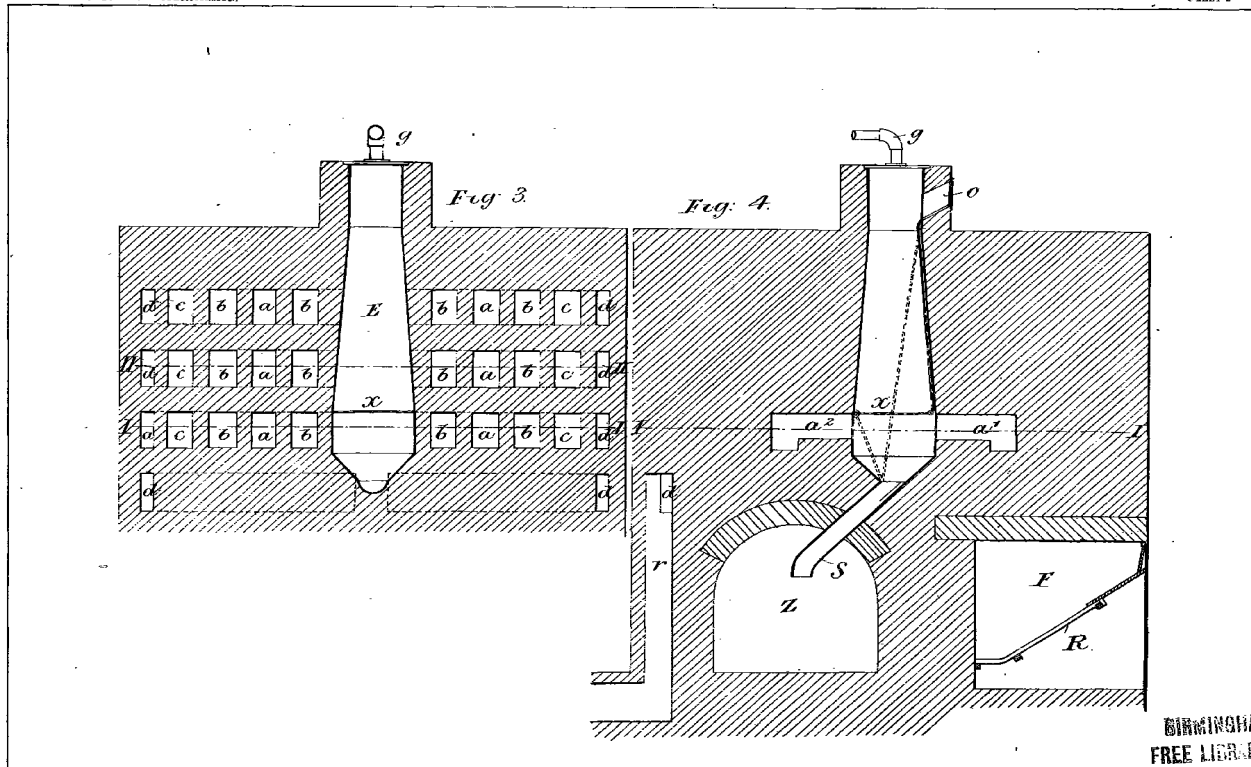
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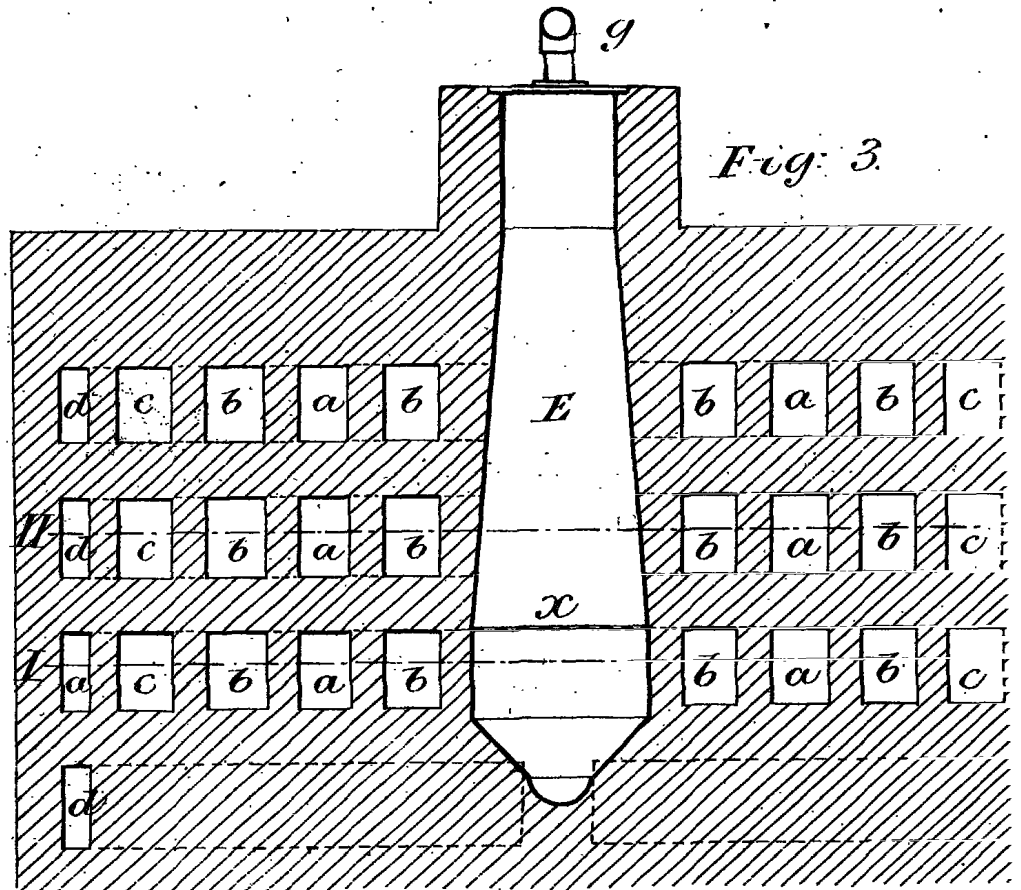


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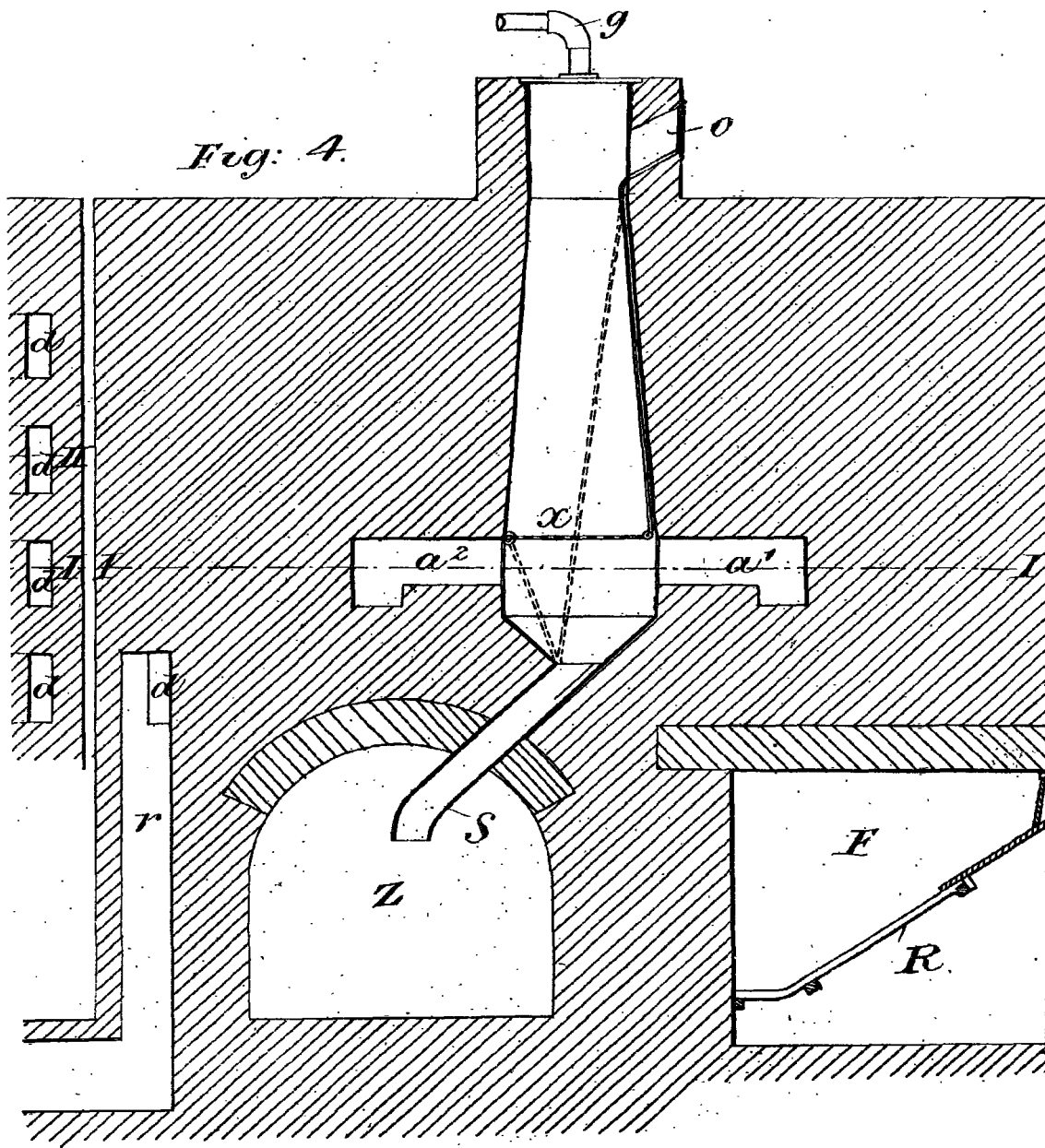
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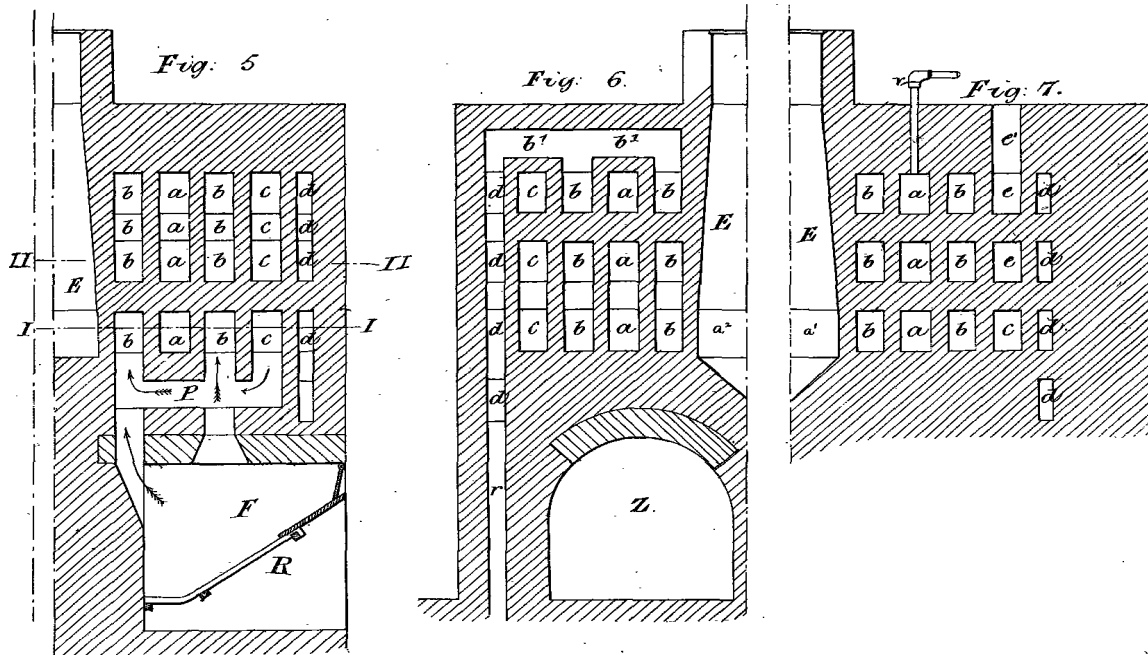
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SHEET 3



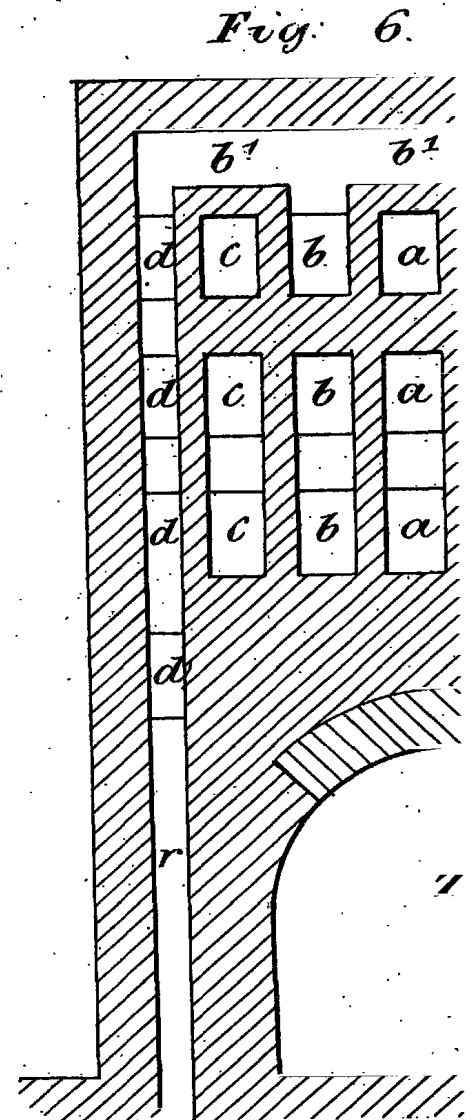
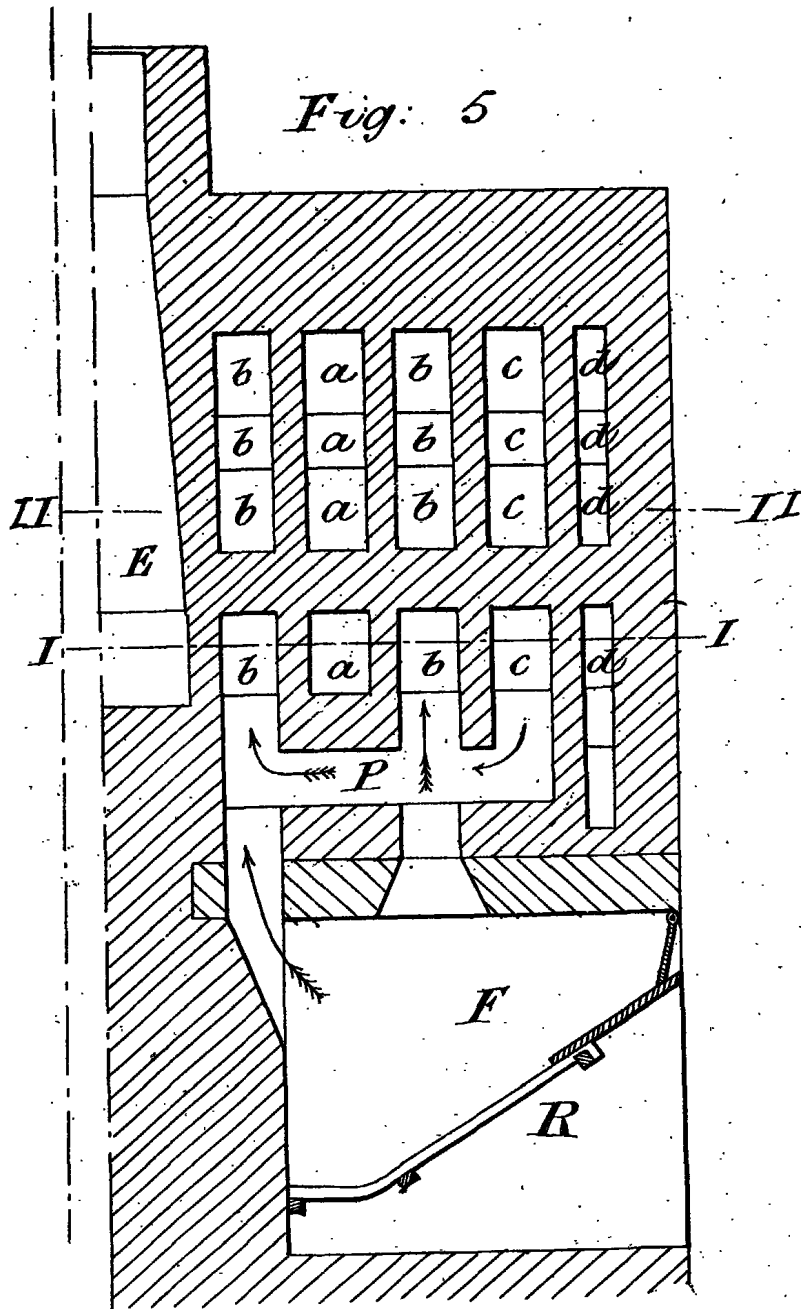
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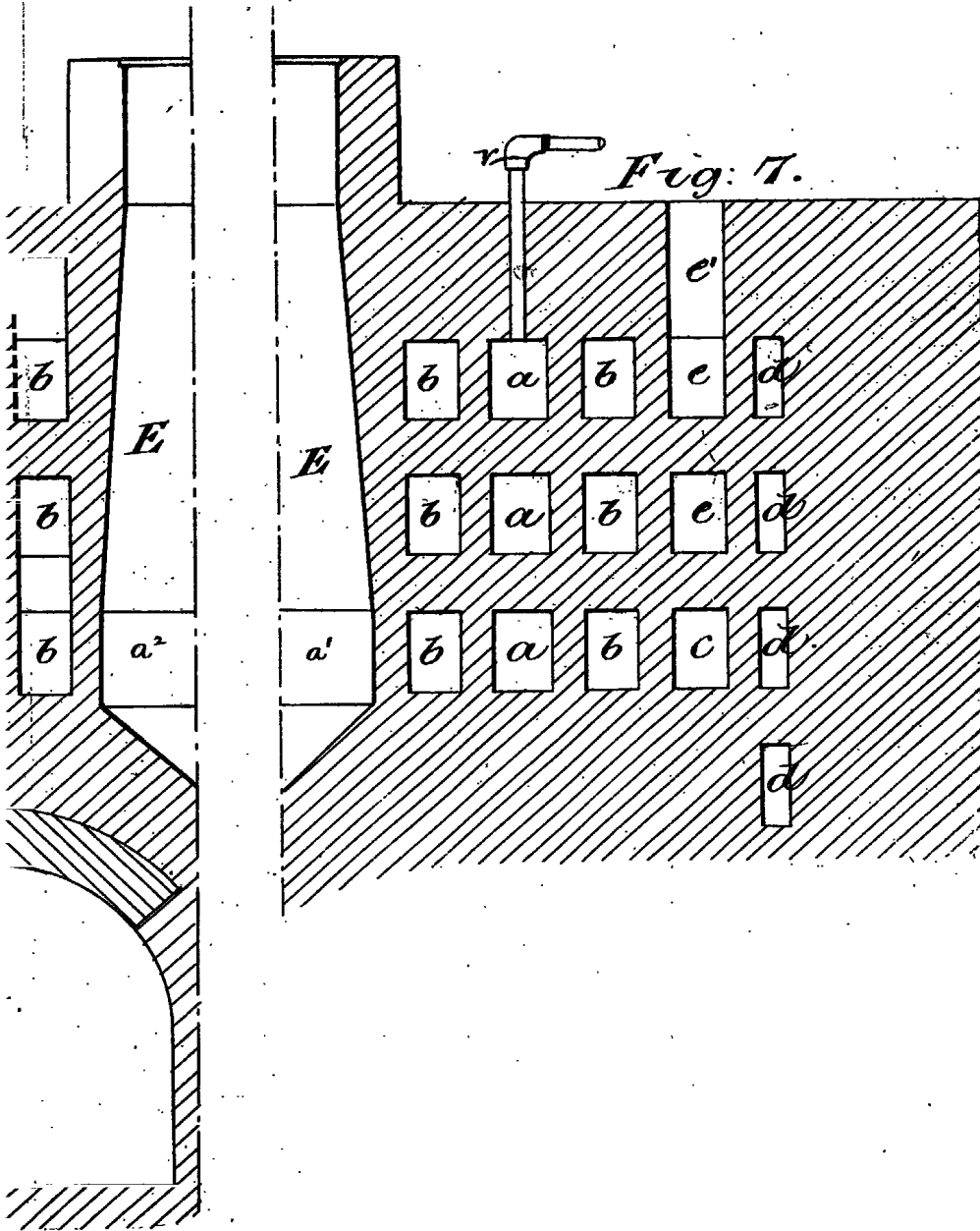
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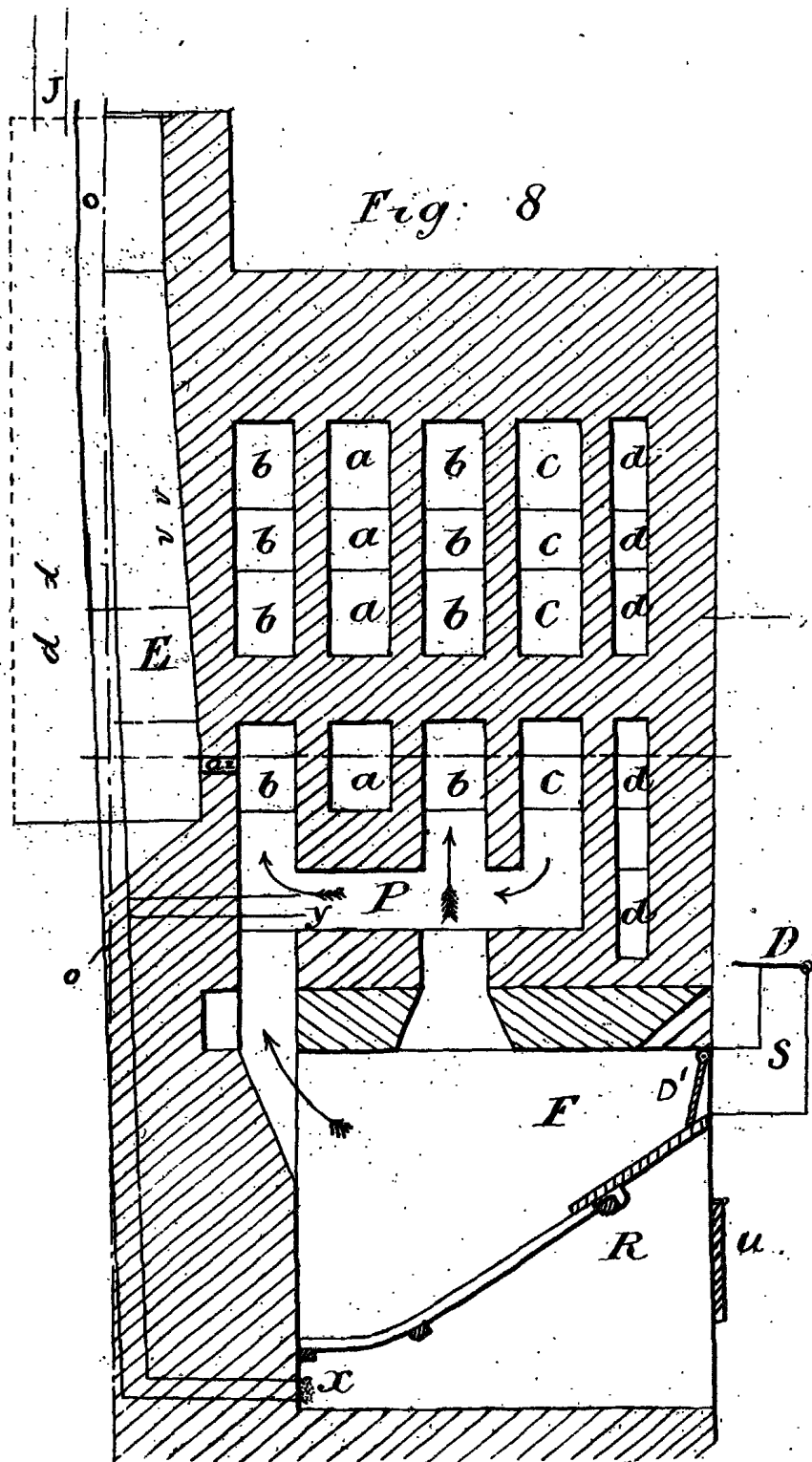


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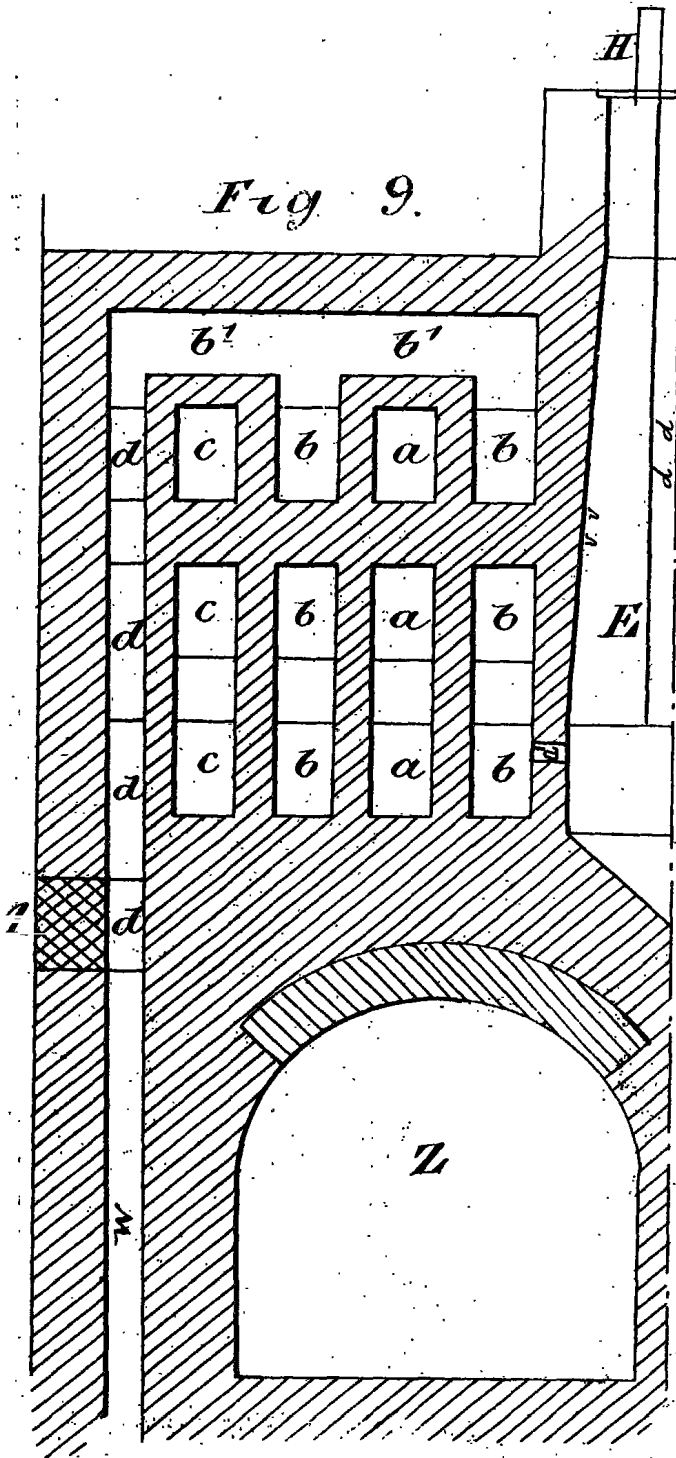


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SHEET 4.

Fig 9.



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N° 16,277



A.D. 1896

Date of Application, 22nd July, 1896

Complete Specification Left, 20th Jan., 1897—Accepted, 27th Mar., 1897

## PROVISIONAL SPECIFICATION.

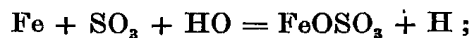
## Improvements in the Production of Pure Hydrogen Gas.

We LEOPOLDO VITTORIO PRATIS and PIETRO MARENGO both of 33 Via Principe Tommaso Turin in the Kingdom of Italy Manufacturers do hereby declare the nature of this invention to be as follows:—

5 In order to reduce the cost of production of pure hydrogen, and thereby to render it practically available, we decompose water by bringing it into contact with waste scrap or other divided form of cast or other iron or other suitable metal such for instance as filings turnings and the like in conjunction with an acid such as sulphuric acid for example; the practical result attained by the process being twofold, *viz.*

- (1) The production of pure hydrogen gas and
- (2) The production of sulphate of protoxide of iron ( $\text{FeOSO}_3$ ) or of the other metal used or other similar salts.

The production of hydrogen gas by our process when iron and sulphuric acid are used for example is founded upon the well known formula



5 (and similarly with other metals and acids) but with a view to facilitating the development of the gas, we employ sulphuric acid at 50° Baumé; and in order to cause the hydrogen gas to be evolved more rapidly, we add the water gradually, so as to generate the heat necessary for a more or less rapid reaction.

Also by increasing the amount of iron beyond the proportion indicated by the above formula the yield in hydrogen is increased, since by such means the surface of the iron, presented for reaction, is extended.

The surplus of iron employed comes into operation as the, nearly anhydrous, protoxide of iron sulphate is converted into hydrated or crystallized sulphate of protoxide of iron.

By this process hydrogen gas is obtained most economically inasmuch as the value of the sulphate of protoxide of iron (or of the other metal employed) produced largely covers the cost of production of the hydrogen gas.

The utility of the invention mainly resides in the fact that, as protoxide of iron sulphate (or other similar salt) is obtained by the process the cost of the hydrogen gas proper is reduced to a minimum, or practically to zero.

Dated this 22nd day of July 1896.

JOHNSONS & WILLCOX,  
47 Lincoln's Inn Fields, London, W.C., Agents.

[ Price 8d.]

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*Pratis and Marengo's Improvements in the Production of Pure Hydrogen Gas.*

## COMPLETE SPECIFICATION.

## Improvements in the Production of Pure Hydrogen Gas.

We, LEOPOLDO VITTORIO PRATIS and PIETRO MARENGO, both of 33 Via Principe Tommaso, Turin, in the Kingdom of Italy, Manufacturers, do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

The object of our invention is to reduce the cost of the production of pure hydrogen so as to render it practically available for illuminating and industrial purposes. 5

According to our invention we decompose water by bringing it into contact with iron, preferably in the form of waste scrap, or other divided form of cast or other iron, such for instance as filings, turnings, or iron ores, and the like in conjunction with sulphuric acid, the result being the production of pure hydrogen gas, sulphate of protoxide of iron ( $\text{FeOSO}_3$ ) being produced in the process. 10

The production of hydrogen gas according to our invention is founded upon the well-known formula  $\text{Fe} + \text{SO}_3\text{HO} = \text{FeOSO}_3 + \text{H}$ . To facilitate the development of the gas we preferably employ sulphuric acid at 50° Beaumé and in order to cause the hydrogen gas to be evolved more rapidly water may be added gradually so as to generate the heat necessary for a more or less rapid reaction. By increasing the amount of iron beyond the proportion indicated by the above formula the yield in hydrogen is increased since the surface of the iron presented for reaction is extended, and moreover the excess of iron employed comes into operation as the nearly anhydrous protoxide of iron is converted into hydrated or crystallized sulphate of protoxide of iron. 15 20

We will describe with reference to the accompanying drawings the manner in which our invention may be performed and a plant adapted for the carrying out of the process.

Instead of strictly adhering to the foregoing formula  $\text{Fe} + \text{SO}_3\text{HO} = \text{FeO} \cdot \text{SO}_3 + \text{H}$ , we use the components in the proportion of one third of each, viz., one part by weight of sulphuric acid at 50° Beaumé, one part of iron and one part of water, so that, at the end of the reaction, in the course of which hydrogen gas is evolved, a paste of sulphate of protoxide of iron forms, which may be very readily reduced to the hydrated or crystallized form; or it may be treated so as to recover sulphuric acid from such paste, previously dried, and to obtain  $\text{Fe}^2$ ,  $\text{O}^3$  as a residue. By employing, as aforesaid, the same amount, by weight, of each of the three components the generation of hydrogen gas is assisted in consequence of the large surface of iron presented to the reaction. 25 30

The greater part of the iron employed is recovered when the aforesaid paste is converted into hydrated iron, or when it is desired to regenerate sulphuric acid. The same remark, in fact, may apply to the water employed; such water being intended to promote reaction. The sulphuric acid may be brought into contact with the water and iron, either by means of a tap or valve, controllable by hand; or automatically by a gasometer arranged to be regulated in accordance with the consumption of hydrogen gas; the gasometer being thus adapted to do duty as a regulator of the sulphuric acid supply. It is this possibility of utilizing the residues which makes the process economical; the fact being that, to whatsoever use the said residues may be put, they will in all cases amply repay the cost of production of the pure hydrogen gas. 35 40 45

In the accompanying drawings

Figure 1 is a diagram illustrating the complete arrangement for the production of hydrogen gas according to this invention; and in the other figures are given elevations and sections of three of the apparatus forming part of the said arrangement as hereinafter described. 50

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*Pratis and Marengo's Improvements in the Production of Pure Hydrogen Gas.*

In a boiler A (shewn also in Figures 3, 4 5 and 6) of wrought or cast iron, or of copper internally lined with lead, there is added to each five litres of water, five kilogrammes of filings, or other fragments of iron, wrought or cast, or of iron ore (which may be either rich or poor, so long as it contains five kilogrammes or the desired multiple of 5 kilogrammes of iron).

Water is admitted by turning on the tap 1 which connects the boiler A with the reservoir B fitted with a level or gauge which indicates the number of litres. The iron is charged direct through the upper opening 2, after which the boiler is closed.

Then, by turning on the tap 3 (preferably made of an alloy of 4 parts of lead and 1 part of antimony) connection is made between the boiler A and the sulphuric acid receiver C (the acid being at 50° Beaumé), which receiver is likewise provided with a gauge, indicating the amount of acid contained therein, in kilogrammes.

The reaction, and the consequent generation of hydrogen gas, now quickly set in.

To expel the air from the boiler the plug 4, fitted in the side of the boiler, at about two thirds of its height, is slowly operated, until the gas within attains a sufficient pressure to expel the air. The tap 3 is left open until a quantity of sulphuric acid has passed equal, by weight, to the quantity of water introduced; the object being, to produce the gas at one operation; and, therefore, a boiler of adequate size is required; i.e. one the capacity of which is about double the volume of the iron, water, and acid.

But where the gas is not required to be produced so promptly, the tap 3 need only be turned on from time to time, and left open for a space proportionate to the amount of gas it is desired to obtain; it being borne in mind, that when the requisite amount of acid—equal to that of the water used—has passed through, the operation is at an end.

The pipes 5 and 6 should be made of lead, and be formed with syphons of from 1 to 2 metres each, according to the level of the water in the washing chambers D and E.

These syphons are provided in order to enable acid and water to be supplied during the reaction, so as to overcome the pressure developed in the boiler, which is equal to the columns of washing water. When the gas has been evolved, the lower valve 7 of the boiler is opened; when the protoxide of iron sulphate will be discharged into the receiver F in the condition of a paste. Then after turning on the tap 1, the boiler is thoroughly washed; after which the digester is closed again, and all is in readiness for a fresh charge.

From the boiler the gas passes into the washing chamber D which contains water and may be constructed either of iron, or of copper lined with lead. In this chamber any acid which may have been carried away with the gas during the reaction; is removed and the gas passes on to the other washing chamber E in which is a solution of a salt of lead, so that any traces of hydrosulphuric acid or of arseniuretted or phosphuretted hydrogen which may be contained in the gas are removed. The gas then passes into the gasometer G, passing on its way; through a device at H (shewn in Figures 7, 8, 9 and 10) containing sheets or discs of closely woven wire gauze, placed at predetermined distances apart, as shewn in the drawings.

From the gasometer G, the gas passes through an insulating water valve I; then through an elastic case or chamber L; then it traverses another device M similar to the one at H and lastly passes off by the branch pipes N O P to the place of utilization.

The water valve I and the elastic case L, are provided as additional means of precaution, but they may be dispensed with if preferred.

If the production of hydrogen gas is to take place automatically, there may be substituted, for the hand-operated tap 3, an automatic cock or valve at R (shewn in side elevation and sectional plan in Figures 2 and 2<sup>A</sup>) which is operated from the gasometer during its descent, and is hereinafter described.

By this means the supply of sulphuric acid may be kept up automatically until a given quantity of acid has completed its gas generating reaction, in conjunction with the iron and water contained in the generator; for gas being no longer evolved the gasometer descends, and causes the cock or valve R to close.

Hydrogen gas may also be obtained gradually by means of automatic arrangements

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*Pratis and Marengo's Improvements in the Production of Pure Hydrogen Gas.*

---

acting upon water iron and acid, there being used, in all cases, receivers lined with lead, placed right into the gasometer.

Should it be desired to generate high pressure hydrogen gas, say at a pressure of from 10 to 50 atmospheres, it is only necessary to construct generators capable of resisting the desired pressures; to complete the changes beforehand, or (if preferred) to use pressure regulating supply reservoirs for the purpose; and to transfer the gases, after washing, into suitable collectors.

Hydrogen gas may, by the aforesaid means, be obtained at very high pressures; and, as it may be preserved in such a state of compression, and consequently in a very compact form, it may be readily carried or forwarded from place to place.

The hereinbefore mentioned automatic cock or valve for the introduction of the acid may be made as follows:—

Upon the plug of a cock which is preferably made of an alloy of four parts of lead and one of antimony there is placed a square (or bell crank lever) B, weighted with a counterweight S, which maintains the said plug in its normal or closed position; and on to the other end of the said square or bell-crank lever there is placed a second square D, similarly weighted at E; this weight also tending to retain its square D in the normal or closed position; a joint being formed at F so as to enable the square to turn from G to H<sup>1</sup>, though it cannot descend beyond its normal position. As the projection 8 from the gasometer bell descends (see Figure 1) it bears upon and depresses the square D; the square B, being thereby actuated, causes the plug of the cock A to turn and open the inlet orifice for the admission of sulphuric acid into the apparatus.

As gas is produced, the bell and projection 8 rise and the cock closes again. When the hydrogen gas production ceases, the projection 8 by descending to the extreme limit of its downward stroke, releases the square D, so that the parts return to their normal position, in which the supply of acid is cut off. The movement of the second square from G to H<sup>1</sup>, serves to afford a free passage for the projection 8 during the first ascent of the gasometer. To commence generating gas, the weight S should be turned by hand from M to N.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. The manufacture of pure hydrogen gas by the decomposition of water by means of iron in the presence of sulphuric acid as hereinbefore explained.
2. The manufacture of pure hydrogen by the gradual addition of water to iron in excess and in a divided condition and sulphuric acid as hereinbefore described.

Dated this 19th day of January 1897.

JOHNSONS & WILLCOX,  
47 Lincoln's Inn Fields, London, W.C., Agents.

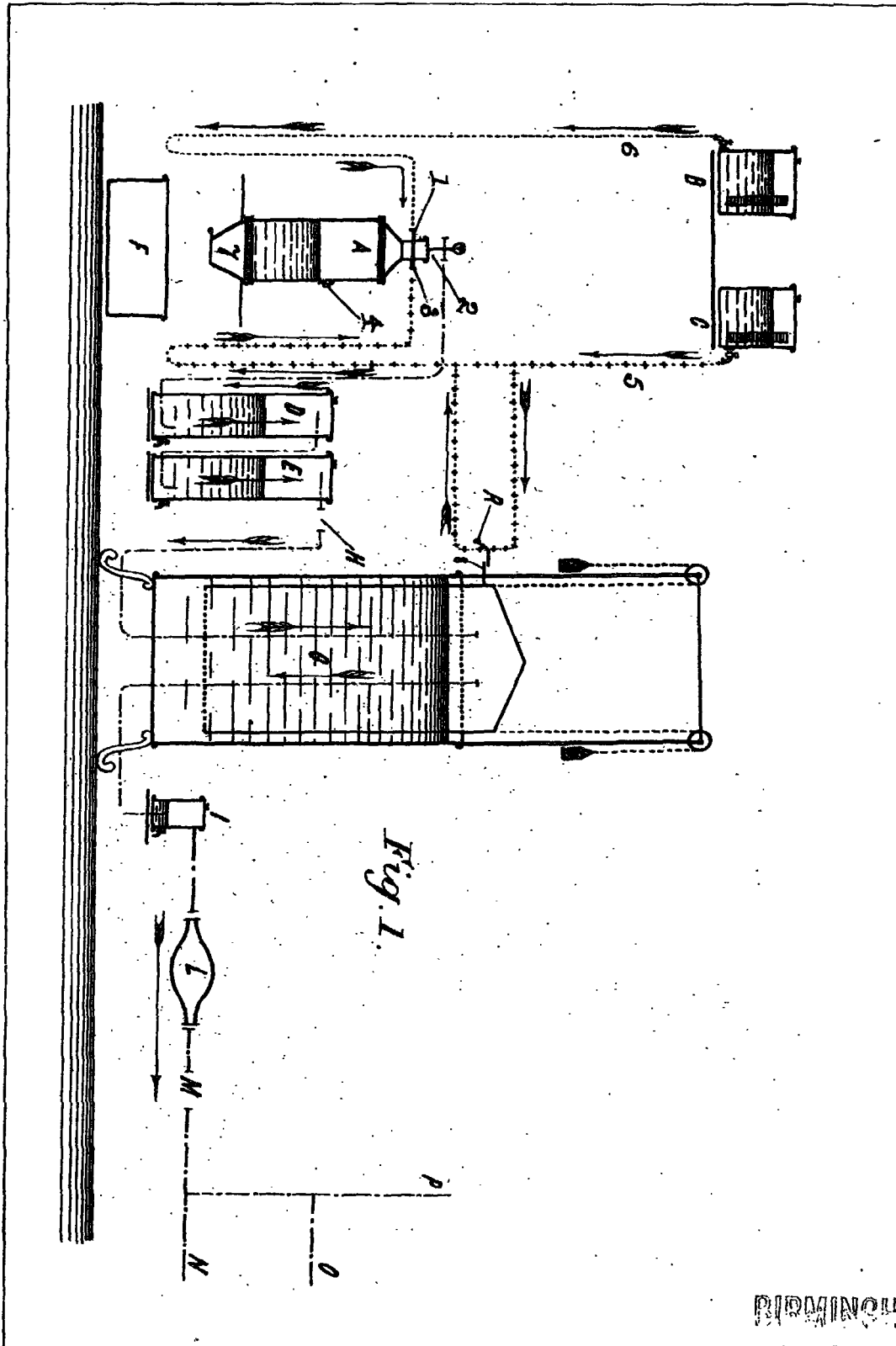
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A.D. 1896. JULY 22. N<sup>o</sup> 16,277.  
PRATIS & another's COMPLETE SPECIFICATION.

(2 SHEETS)  
SHEET 1.



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A.D. 1896. JULY 22. N° 16,277.  
PRATIS & another's COMPLETE SPECIFICATION.

(2 SHEETS)  
SHEET 2

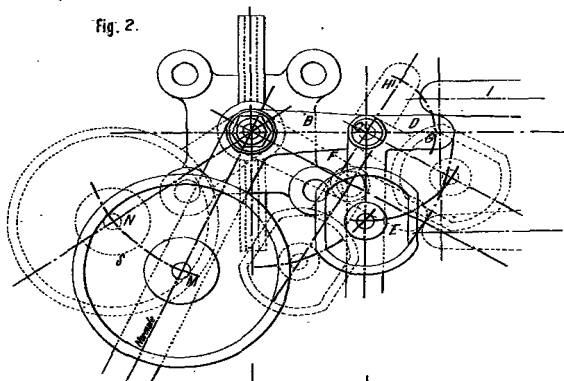


Fig. 2<sup>A</sup>

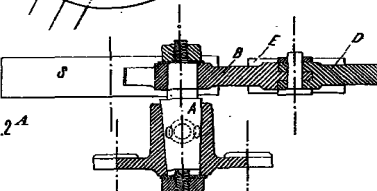


Fig. 7



Fig. 9



Fig. 8



Fig. 10

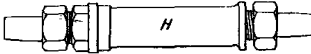


Fig. 3

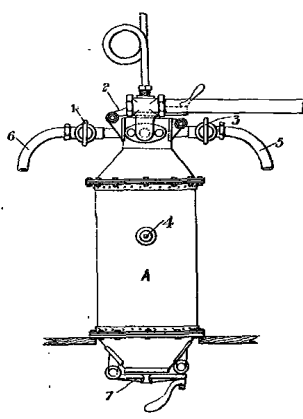


Fig. 5

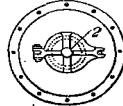


Fig. 4

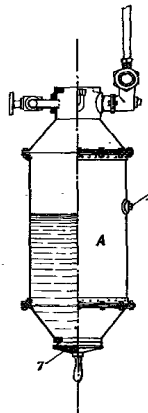
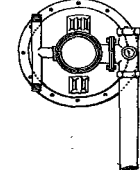


Fig. 6



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A.D. 1896. JULY 22. N<sup>o</sup>. 16,277.

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Fig. 2.

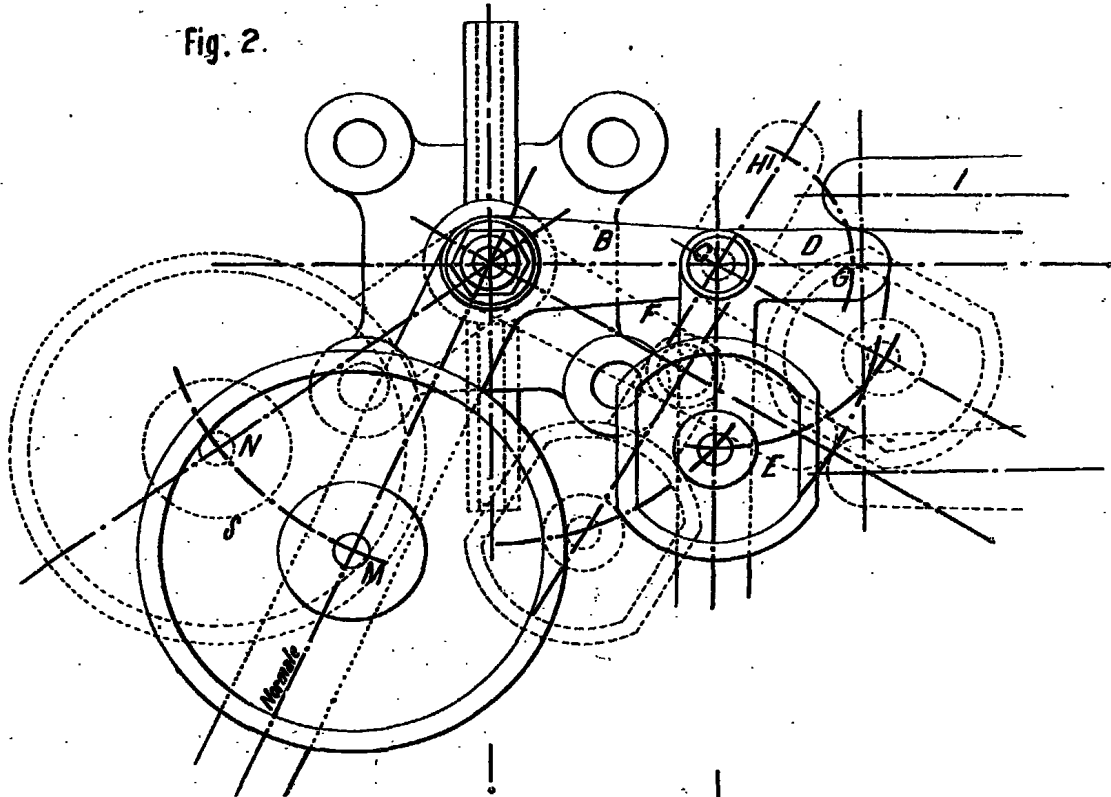


Fig. 2<sup>A</sup>

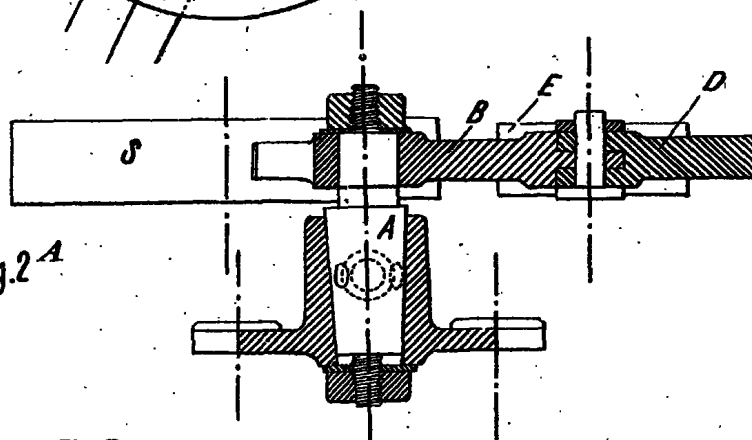


Fig. 7



Fig. 8



Fig. 9

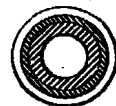
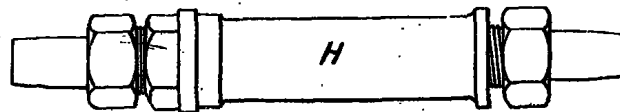


Fig. 10



(2 SHEETS)  
SHEET 2.

Fig. 3

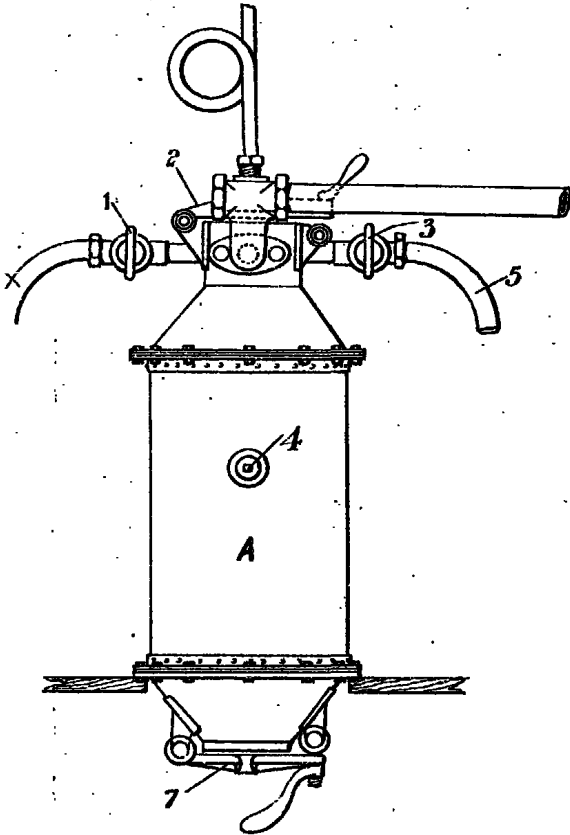


Fig. 4

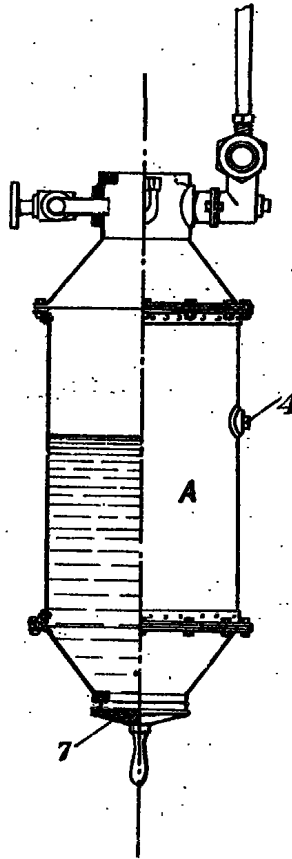


Fig. 5

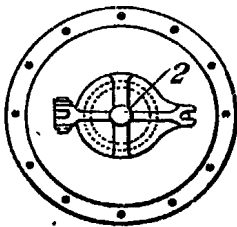
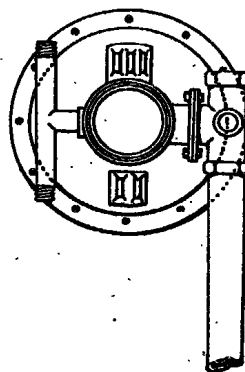


Fig. 6



[This Drawing is a reproduction of the Original on a reduced scale.]

N° 16,277A



A.D. 1896

*Date of Application, 22nd July, 1896**Complete Specification Left, 20th Jan., 1897—Accented, 10th Apr., 1897***PROVISIONAL SPECIFICATION.****The Utilization of Hydrogen Gas for the Obtainment of Light, Heat, and Power.**

We LEOPOLDO VITTORIO PRATIS and PIETRO MARENGO both of 33 Via Principe Tommaso, Turin in the Kingdom of Italy, Manufacturers, do hereby declare the nature of this invention to be as follows:—

Hydrogen gas, it is well known, in itself possesses no illuminating power and the attempts which have been made to impart such power to it by means of lime have led to no results of any practical value for general use.

We have after a long series of experiments succeeded in rendering hydrogen gas capable of being utilized for illuminating purposes through the agency of mantles or cages such as those of Auer, Cosmos and the like or of platinum gauze netting or fabric or of mixed mineral and metallic matter or of the oxides of metallic earths according to the place where the gas is utilized or with the amount of light that is wanted. By such means we utilize hydrogen for obtaining light but we apply also hydrogen to the obtainment of heat and power such gas being capable of producing a greater amount of heat than can be produced by any other gas.

We intend to accomplish the distribution of hydrogen and its utilization for the obtainment of heat and power through the ordinary means employed for other gas; that is it may be distributed by means of the usual system of main and branch pipes and utilized by means of the ordinary heaters, furnaces, kitchen ranges, engines, and the like.

It being possible to compress hydrogen gas to a very high pressure, and to keep it at such high pressure we propose to use the said gas for the illumination of trains wagons, vehicles, and in general in all cases where the illuminating gas has to be forced into and carried in a small space from place to place.

Dated this 2nd day of September 1896.

JOHNSONS & WILLCOX,  
47 Lincoln's Inn Fields, London, W.C., Agents.

**COMPLETE SPECIFICATION.****The Utilization of Hydrogen Gas for the Obtainment of Light, Heat, and Power.**

We, LEOPOLDO VITTORIO PRATIS and PIETRO MARENGO, both of 33 Via Principe Tommaso, Turin, in the Kingdom of Italy, Manufacturers do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

Hydrogen gas, it is well known, in itself possesses no illuminating power and  
[Price 8d.]

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*The Utilization of Hydrogen Gas for the Obtainment of Light, Heat, and Power.*

the attempts which have been made to impart such power to it by means of lime have led to no results of any practical value for general use.

We have, after a long series of experiments, succeeded in rendering hydrogen gas capable of being utilized for illuminating purposes through the agency of mantles, or cages, such as those of Auer, Cosmos, and the like, or of platinum gauze, netting, or fabric, or of mixed mineral and metallic matter, or of the oxides of metallic earths, according to the place where the gas is utilized, or with the amount of light that is wanted.

By such means we utilize hydrogen for obtaining light, but we apply also hydrogen to the obtainment of heat and power, such gas being capable of producing a greater amount of heat than can be produced by any other gas.

We may accomplish the distribution of hydrogen and its utilization for the obtainment of heat and power through the ordinary means employed for other gas; that is, it may be distributed by means of the usual system of main and branch pipes and utilized by means of the ordinary heaters, furnaces, kitchen ranges, engines and the like.

It being possible to compress hydrogen gas to a very high pressure and to keep it at such high pressure, we propose to use the said gas for the illumination of trains, wagons, vehicles, and in general in all cases where the illuminating gas has to be forced into, and carried in, a small space from place to place.

We will describe with reference to the accompanying drawings means by which our invention can be carried into practical effect.

In Figure 1 is shewn in elevation a burner suitable for burning hydrogen gas according to our invention. It consists as follows:—A small central tube (shewn in part section and part elevation in Figure 2 and in plan in Figure 3) is provided for the admission of gas. Over this tube is fitted a tubular piece (shewn in part section and part elevation in Figure 4 and in plan in Figure 5) in which there are a number of perforations (say four) for the admission of air and preferably of a cross-sectional area of 6 millimètres each. The cover or casing (shewn in part elevation and part section in Figure 6 and in plan in Figure 7) has also a number of perforations or vents, say four, for the admission of air, but it is rotatable by means of the handles shewn, so that the air-supply can, at will, be turned on, increased, reduced, or cut off altogether. The slot A therein, working over a screw B in the tubular piece Figures 4 and 5 serving to control this rotary motion of the case. The mantle holder, shewn in section in Figure 8 and in plan in Figure 9 is secured onto the tubular piece, Figures 4 and 5 it being screwed to a washer C screwed on previously, and serving as a counter nut. In this mantle holder there are arranged, at equal distances apart, three small discs *a* of close woven wire-gauze, which assist the proper distribution of the gas through all the outlets, and also serves to protect the flame from direct action of the hydrogen gas issuing from the tube Figures 2 and 3. The outer case Figures 6 and 7 serves to prevent the admission of air while the hydrogen gas is being ignited, the object being, to avoid the formation of any explosive mixture within the mantle which, if made of a mineral substance, would burst were an explosion to occur. When a flame has been kindled, the casing, Figures 6 and 7, is turned, and air is admitted to the hydrogen, so that oxy-hydrogen gas is produced, and both the heating and illuminating power of the flame are greatly increased.

We have found the illuminating power to be equal to about 200 candles with a consumption of 125 litres of hydrogen gas per hour. To a burner like that shewn in Figure 1 we have fitted a mantle, only 30 millimetres high and for the tube shewn in Figures 2 and 3 we have provided one with one gas inlet orifice about 1 square millimetre wide; and have supplied a mantle carrier (Figures 8 and 9) with an outer diameter of 21 millimetres. The intensity of the light we obtain by such means equals 50 candle power, with a consumption of hydrogen gas not exceeding 40 litres per hour. Figures 10 and 11 shew the gallery or chimney holder.

In the burner, constructed as hereinbefore described, we obviate internal ignition,

N<sup>o</sup> 16,277A.—A.D. 1896.

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*The Utilization of Hydrogen Gas for the Obtainment of Light, Heat, and Power.*

which is unavoidable if one of Auer von Welsbach's burners be used in connection with our pure hydrogen gas.

The mantle, shewn in elevation and plan in Figures 12 and 13, consists of platinum wire, varying between  $\frac{1}{10}$  and  $\frac{1}{20}$  of a millimetre in diameter. Its meshes are formed either by interweaving like a warp and weft fabric, or looped, as by knitting, or in any other manner, provided the fabric offers a great number of points for producing incandescence. Its weight may vary from 0.4 to 2 grammes per mantle. The central support, shewn in elevation and plan in Figures 14 and 15, is made of porous porcelain or steatite. It is shaped with facets and re-entering or inwardly bent angles, so as to enable it to utilize the maximum amount of heat, relatively to the extent of its surface of exposure. The burner holder D is "cupped" at E to fit the said central support.

The small lamp which is shewn complete in Figure 16 is particularly fitted for use as a suspension lamp, where the object is to direct the light downwards; and it is also intended to be used in those cases where the lamp, being liable to sudden movements, shocks, or jerks, cannot have an ordinary mantle of mineral material applied to it.

In order to derive full advantage from the use of hydrogen gas in driving gas engines of any type or construction, it is necessary to provide inlet ports for the hydrogen gas and air, that for the air being of a sectional area of, or about, 18 times that for the hydrogen gas, by which means there will be obtained an explosive mixture calculated to ensure perfect combustion and the obtainment of considerable power amounting to about double that hitherto obtained in even the most improved gas engines.

As the oxy-hydrogen flame, obtained from hydrogen gas, possesses a great many units of heat, or very great heating power, we have applied to cooking ranges and gas stoves, the same principle on which is based the construction of our burner for purposes of illumination, for which purpose we combine with an air fan or suction device an arrangement such as is shewn in part elevation in Figure 17 and in sectional plan of underside in Figure 18. The diaphragm A operated by a lever B covers and uncovers perforations in a funnel C. The flame may thus be controlled, so as to increase or diminish the intensity of heat at will, and avoid the formation of explosive mixtures at the time of ignition. The hydrogen gas supply is regulated by slight movements imparted to the tap D, shewn in elevation in Figure 19, and the admission of air is controlled by means of the lever B. Unless the currents of gas and air, respectively, are properly regulated, the hydrogen would become ignited at the very orifice E. The amount of heat secured by means of our burner using pure hydrogen gas is double the amount hitherto obtained in the most improved cooking stoves heated by ordinary illuminating gas.

Having now particularly described and ascertained the nature of this invention and in what manner the same is to be performed, we declare that what we claim is:—

1. The obtainment of light by burning hydrogen gas in contact with hoods, or mantles, of platinum gauze netting, or fabric, or of oxides of the metallic earths, or of mixed mineral and metallic matter, substantially as hereinbefore described.

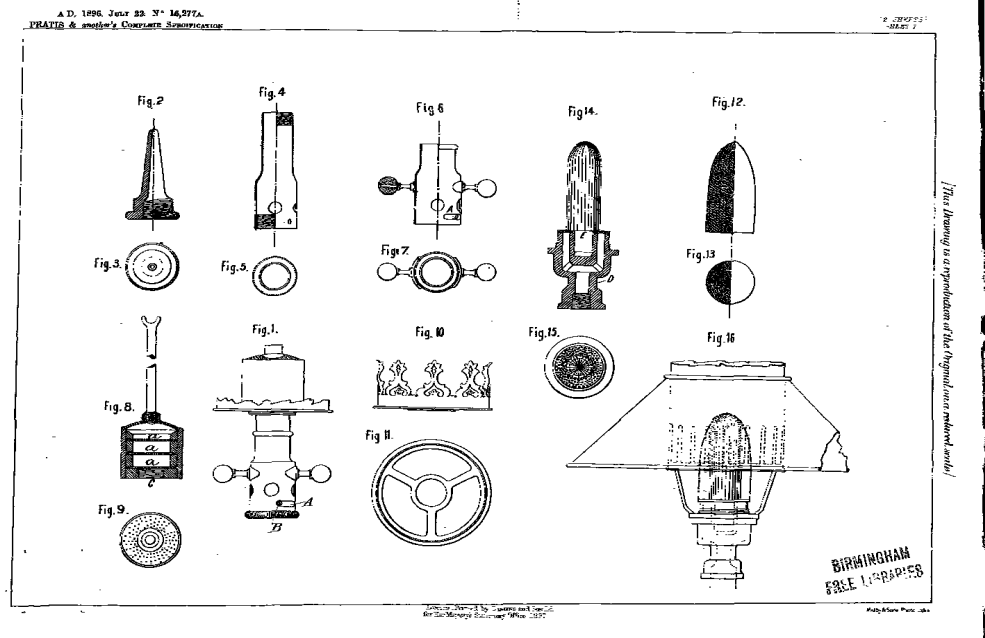
2. The utilization of hydrogen gas for the obtainment of heat or power, substantially as hereinbefore described.

3. The utilization of hydrogen by compressing it into containers and its application to the illumination of trains, or other vehicles, substantially as hereinbefore described.

Dated this 19th day of January 1897.

JOHNSONS & WILLCOX,  
47 Lincoln's Inn Fields, London, W.C., Agents.

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A.D. 1896. JULY 22. N° 16,277A.

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Fig. 2.

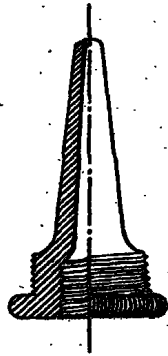


Fig. 4.



Fig. 6.

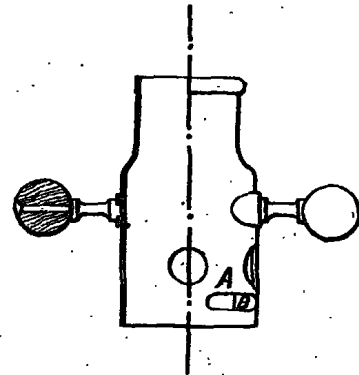


Fig. 3.

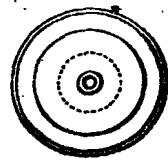


Fig. 5.

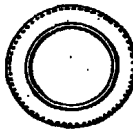


Fig. 7.

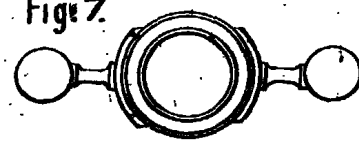


Fig. 1.

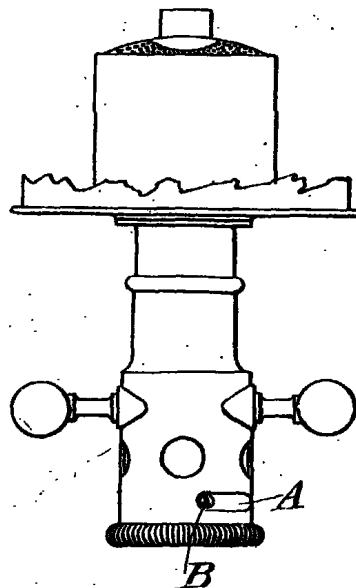


Fig. 10.



Fig. 8.

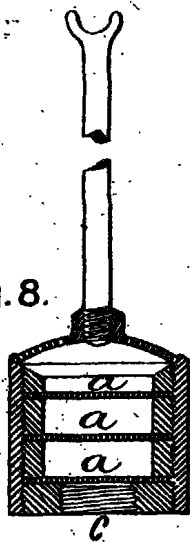


Fig. 11.

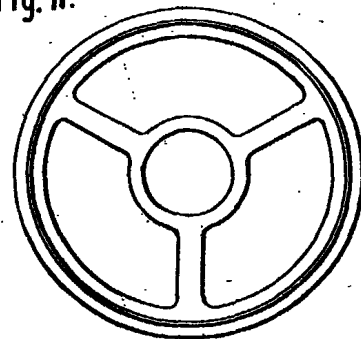
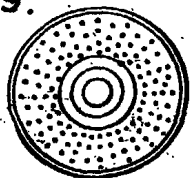


Fig. 9.



(2 SHEETS)  
SHEET 1.

Fig.14.

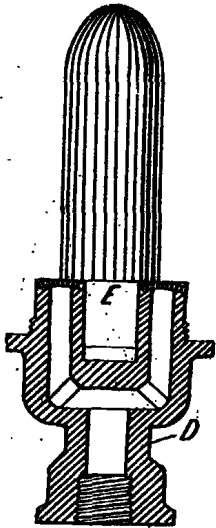


Fig.12.

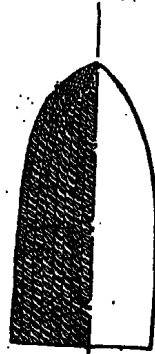


Fig.13.



Fig.15.

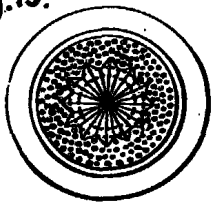
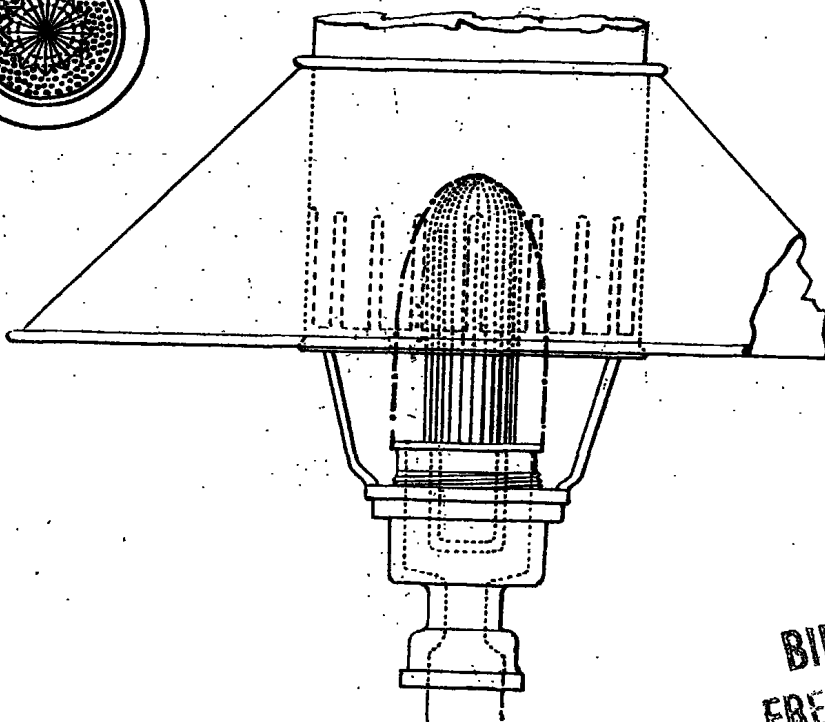


Fig.16

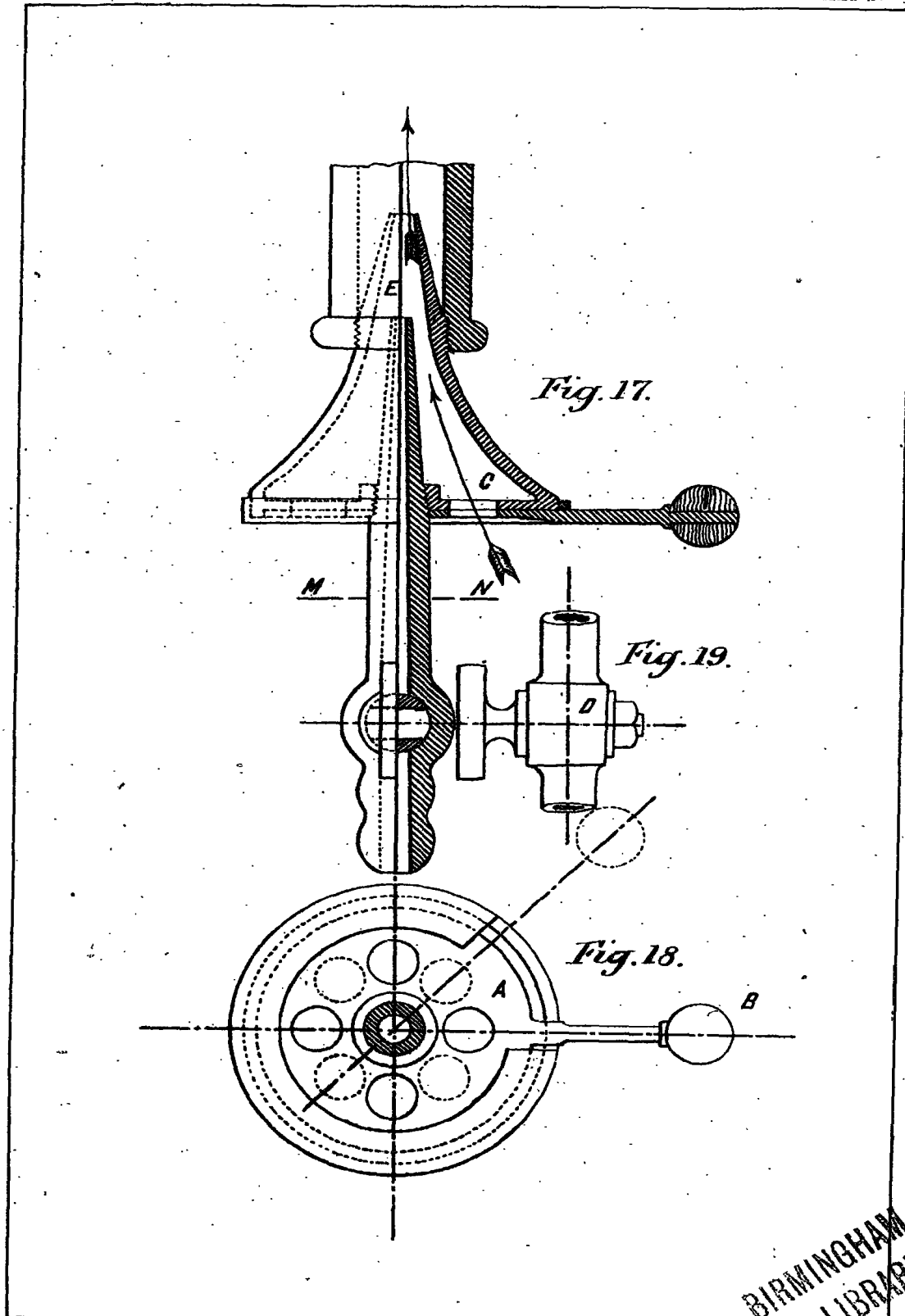


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(2 SHEETS)  
SHEET 2.



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N° 23,663



A.D. 1896

*Date of Application, 24th Oct., 1896—Accepted, 13th Feb., 1897*

COMPLETE SPECIFICATION.

**New and Useful Improvements in the Apparatus for the Production of Oxygen and Hydrogen by Electrolysis.**

We POMPEO GARUTI, Professor and RICCARDO POMPILI Proprietor both of Via Foggia No. 11 Naples Italy, do hereby declare the nature of our said invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

5 The object of our present invention is to introduce a new and useful improvement already patented (No. 16588 of 1892) for the production of oxygen and hydrogen by means of electrolysis.

This improvement consists in the use of metallic diaphragms of a suitable resistance, which are perforated in their lower part by numerous small holes.

10 By this means the resistance to the decomposition of the water is much diminished which forms a very great advantage in the producebleness of the apparatus.

In order to render this improvement more conceivable it is necessary to give a brief description of the electrolysing apparatus and to illustrate the same by the  
15 annexed drawings in which

Figure 1. shows a longitudinal vertical section through the centre of the apparatus.

Figure 2. is a corresponding horizontal section of one end of the same.

Figure 3 is a vertical cross section of the same.

20 Figure 4 is a broken plan view of the conductors and electrodes.

Figure 5 is a section on line *w—v* of Figure 5<sup>A</sup>.

Figure 5<sup>A</sup> is a lateral view of Fig. 5.

Figure 5<sup>B</sup> is a section on line *x—y* of Figure 5<sup>A</sup>.

Figure 6 is a prospect view of the forks *l* with a longitudinal section of the  
25 same.

Figure 6<sup>A</sup> is a section on line *Z—Z* of Fig. 6.

Figure 7 is a vertical projection of the metallic perforated diaphragm.

The same letters of reference indicate the same parts of the apparatus.

The apparatus of our invention with its new improvement is constructed as  
30 follows.

In a tank *A* of wood or other material lined internally with an iron plate *a*—the same can be also made altogether of iron,—is placed the electrolyzing apparatus immersed in the liquid to be electrolyzed. The tank is isolated from the ground by the insulators *M*.

35 The electrolyzing apparatus consists of a case *A*<sup>1</sup> turned upside down which by means of longitudinal diaphragms *n* divides internally into cells *E*.

The case is made of iron steel or other metal and is open only at the bottom so as to permit the water to enter in the cells.

The anodes *b* and the cathodes *c* are placed one in each cell alternately  
40 taking care that each anode is between two cathodes and each cathode between two anodes. This disposition prevents thus the mixing of the gases which as they form pass the oxygen only in the anode cells and the hydrogen in the cathodes.

The cells *E* have openings *F* at the top, through which the gases escape  
45 and enter in the chambers *G*, situated at the top of the apparatus. There are

[Price 8d.]

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N° 23,663.—A.D. 1896.

*Apparatus for the Production of Oxygen and Hydrogen by Electrolysis.*

two chambers G, one serves to receive the oxygen and communicates with all the anodes cells, the other receives the hydrogen and communicates with the cathode cells.

On the chambers G are mounted small copper pipes *g*, which are connected to the big distributing pipes by means of the insulating tubes *h* made of glass or 5 porcelain.

To the tops of each chamber is soldered a receptacle H of sufficient diameter and height which forms a hydraulic closing preventing the escape of gas at the junction of the said tube *g* with the tube *h*.

Two conductors one positive B, and one negative *c* rest over the top of the tank 10 and extending down to the bottom of the apparatus enter through chambers D without having electrical contact therewith. Arms O branch off from the conductors and connect themselves with the electrodes. These conductors in their passage through the water are covered with a coating of caoutchouc *b'* insulating them from the liquid and their extremities terminate in a junction of copper *b''* 15 where the current enters. The chambers D serve to collect the gas that forms on the surface of the conductors the gas passing through an opening made at the upper part of the said chamber into the cells that contain the same gas.

The electrodes are isolated from the diaphragms *n* by combs I made of wood or other non conducting material, the teeth of which enter into the cells and fill out 20 the spaces between the electrodes and the diaphragms to prevent them from coming into contact, one with the other the combs are fastened to longitudinal beams J, lying on the bottom of the tank and are cut out at the points of the teeth so as to allow free passage of the gases to the top of the cells E.

The electrolyzing apparatus does not extend quite to the bottom of the tank but 25 rest upon transversal beams—as shown in the drawings, so that any sediment which the water deposits does not interfere with the working of nor damage the apparatus.

To prevent the electrodes from touching the top of the cells every electrode has at each end at the top a fork *l* of material similar to that of the combs I, this fork *l* 30 has two teeth T between which the electrode enters. The whole fork resting between two diaphragms occupies transversally the whole width of the cell touching the top of the cell.

In order to be able to lift out the apparatus out of the tank there are two 35 handles L.

In the apparatus of our invention with its improvements of which will be spoken hereafter, in relation with the diaphragms we use an alkaline electrolyte that is; drinking water or rain water with 25 p.c. of soda, or caustic potash.

The water in the tank must be always level with the top of the chamber G so as to give to the gases the requisite pressure. 40

The complete immersion of the apparatus permits to detect quickly any contact between the electrodes, and the diaphragms such contact being indicated by gas bubbles rising to the surface of the liquid in the tank.

In an electrolyzing apparatus the superficial extension of the electrodes must be calculated according to the force of the current. 45

In the apparatus above described in order to obtain a perfect working the electrode must have one half square decimeter of surface for each ampere of current and must have a height not exceeding 0.14 m.

Having thus described our electrolyzing apparatus we describe now in what consists the new improvements introduced in the same. According to the above 50 description the metallic diaphragm is uninterrupted and forms therefore from the top to the bottom a complete division of the cells and the electrodes forming thus a resistance not to the passage of the current but to the decomposition of the molecules of the water. Generally the electrodes do not extend to the full height of the cells, but terminate at some distance from the top of the same if therefore 55 instead of the electrodes there is a direct communication of the liquid between the cells, the said resistance is much diminished. To obtain this very important object

N° 23,663.—A.D. 1896.

3

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*Apparatus for the Production of Oxygen and Hydrogen by Electrolysis.*

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we modify the structure of the diaphragms by piercing in its lower part up to a little height, practically of 0.05 m. small holes of one millimetre of diameter these holes must be as near as possible one to the other without weakening too much the iron plate of the diaphragms *n*. This modification facilitates the orientation of the  
5 molecules of the water during the phenomenon of the electrolysis diminishing the resistance to the decomposition of the water conserving the same the perfect division of the two gases. Figure 7 shows a part of the diaphragm *n* perforated by small holes as described above.

Having now particularly described and ascertained the nature of our said inven-  
10 tion and in what manner the same is to be performed we declare that what we claim is :—

In an apparatus of our invention as described above for the production of oxygen & hydrogen by means of electrolysis the metallic diaphragms which are perforated in their lower part up to a little height by small holes as near as possible to each  
15 other as substantially described and illustrated in the drawings.

Dated this 23rd day of October 1896.

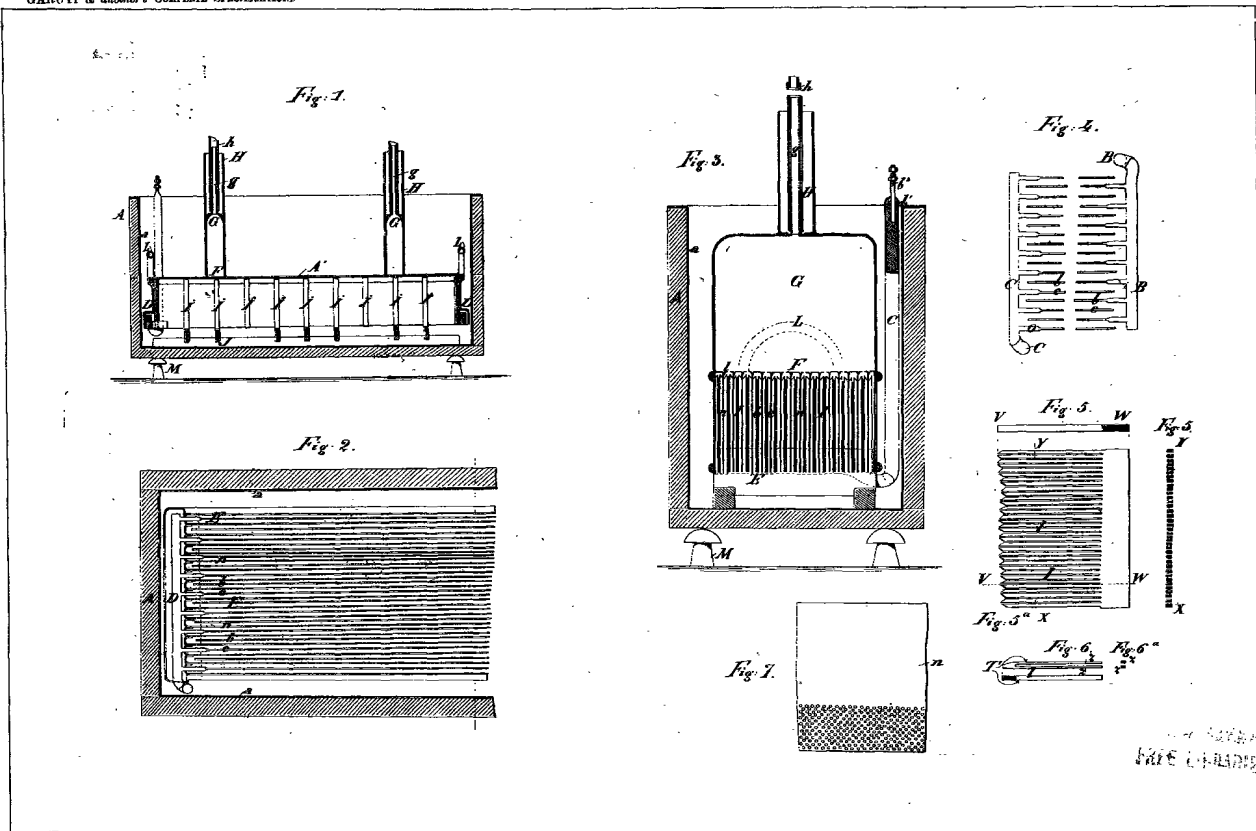
GEORGE BARKER,  
77 Colmore Row, Birmingham, Agent.

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London : Printed for Her Majesty's Stationery Office, by Darling & Son, Ltd.—1897

A.D. 1896. Oct. 24. N<sup>o</sup>. 23,663.  
GARUTI & another's COMPLETE SPROUTING.

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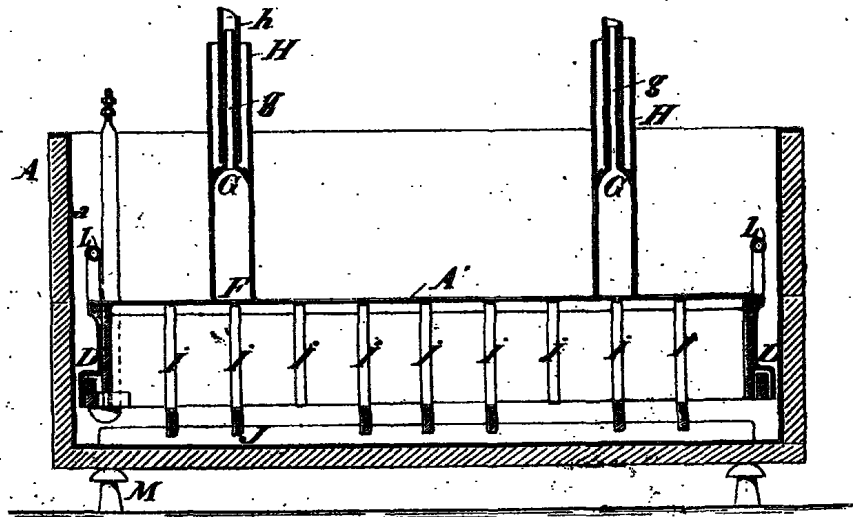
[This Drawing is a reproduction of the Original on a reduced scale]

Printed by J. H. M. and Son, Ltd.  
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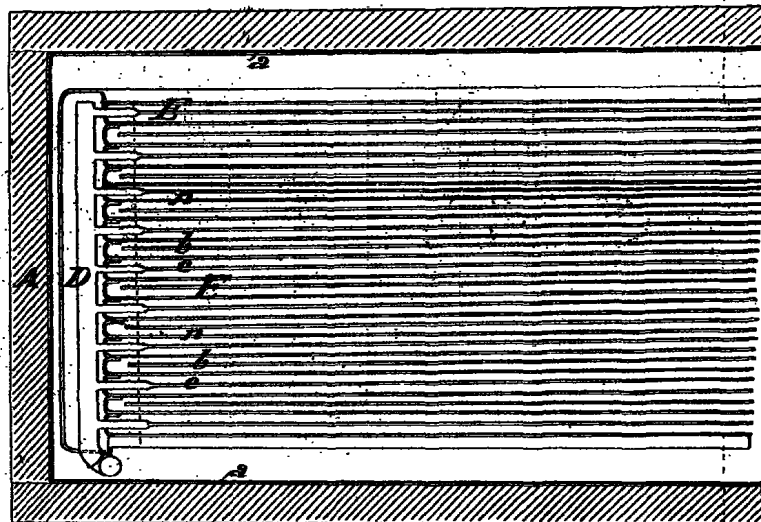
M. J. & S. 1897

A.D. 1896. Oct. 24. N<sup>o</sup>. 23,663.  
GARUTI & another's COMPLETE SPECIFICATION.

*Fig. 1.*



*Fig. 2.*





(1 SHEET)

Fig. 3.

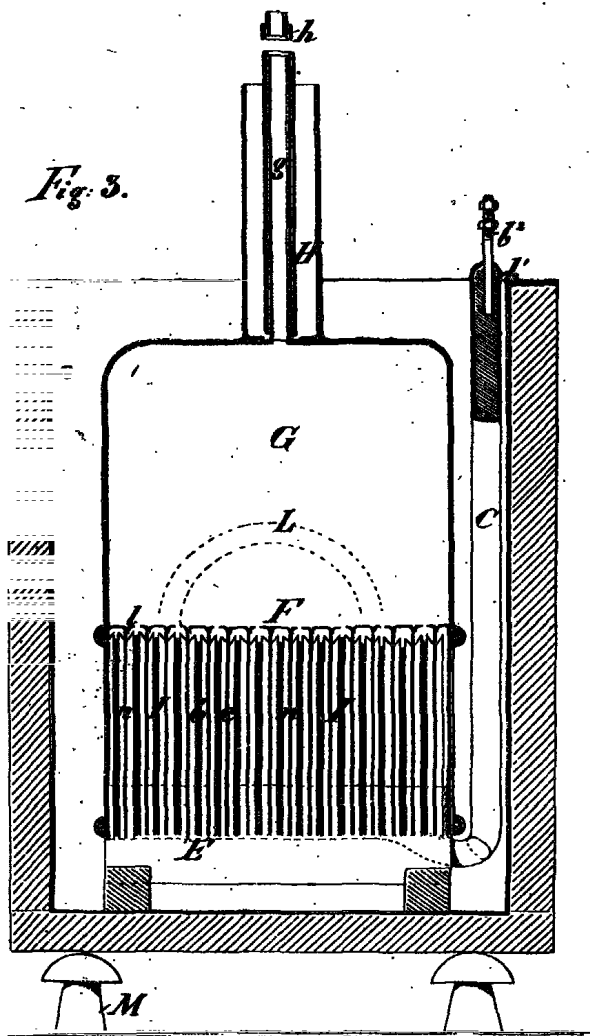


Fig. 4.

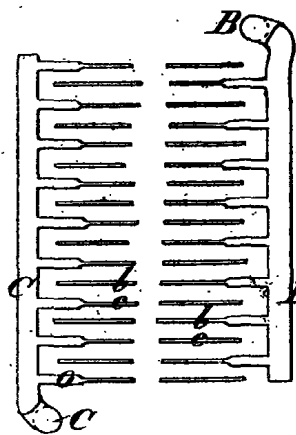


Fig. 5.

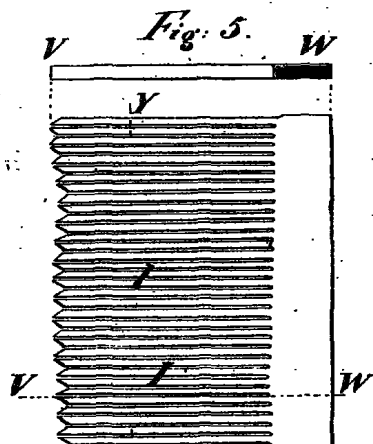


Fig. 5.



Fig. 5<sup>a</sup> X

Fig. 6.



Fig. 6<sup>a</sup>

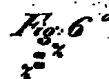
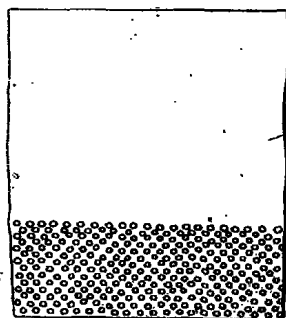


Fig. 7.



[This Drawing is a reproduction of the Original on a reduced scale]

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N<sup>o</sup> 28,721

A.D. 1896

Date of Application, 15th Dec., 1896

Complete Specification Left, 13th May, 1897—Accepted, 11th Dec., 1897

## PROVISIONAL SPECIFICATION.

**“Improvements in the Production of Hydrogen Gas and in Apparatus therefor.”**

I, REGINALD GEORGE LEVENTHORPE, of No. 9 Gloucester Terrace, Hyde Park, in the County of Middlesex, Gentleman, do hereby declare the nature of this invention to be as follows:—

The hydrogen gas is produced in the well known manner by passing steam  
5 through one or more heated retorts charged with iron borings.

According to my invention I arrange the retorts in a brickwork setting or structure that comprises a so-called producer, and by gases produced therein and proceeding therefrom. I heat the retorts externally and I employ the surplus heat of the said gases on their way from the retort chamber to the chimney for  
10 the heating of a boiler which supplies the steam required for passing through the retorts.

The retorts have by preference end covers fastened by hinged bolts and the joints are made with a thin copper strip which is pressed by a bead on the retort into a corresponding groove turned in the cover. The pipes connected to the  
15 retorts are of weldless steel swelled out conically at the end; the conical part making joint with the rounded male end of a fitting screwed into the retort a union nut screwed on the fitting holding the parts together. The retorts are provided with safety valves.

The steam in passing through the heated retorts separates more or less into  
20 oxygen and hydrogen, the former being taken up by the iron borings, while the hydrogen under a pressure derived from that of the steam in the boiler (though usually much lowered) is passed into a gasholder to be stored and utilized as required I may use an ordinary gas holder or gas holders but on the score of economy I prefer to use two storing cylinders placed horizontally side by side  
25 and in connection therewith one two or more water tanks placed at such an elevation as to represent a suitable head or pressure under which the gas is to be supplied to the place of application. A governor may be used allow the water in the cylinders to run away at the atmospheric pressure if desired. These cylinders each with its tank are intermittently or alternately either in use or  
30 being charged. I would here note that an arrangement as hereinbefore described is particularly suitable for supplying the liquor in tan pits with hydrogen gas according to the rapid tanning process described in the Specification of Bake & Leverett's Patent No. 13195 dated 7th July 1894.

I shall now describe one suitable form of apparatus for carrying out the process  
35 described. The producer furnace and the retort chamber are arranged side by side in the same brick structure. The producer furnace narrows towards the bottom and is arched at the top. It is charged with coke and supplied with a restricted quantity of air from flues laterally entering the ashpit below the grate so as to produce carbonic oxide which gas passes off through openings in the

[Price 8d.]

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N° 28,721.—A.D. 1896.

*Improvements in the Production of Hydrogen Gas and in Apparatus therefor.*

arched top into a combustion chamber where it is converted partially or as desired into carbon dioxide by a secondary and similarly restricted supply of air which is conveyed to the combustion chamber as described hereafter.

These gases are then admitted to the retort chamber and being deficient in oxygen will have no injurious action on the retorts. The retorts are cylindrical 5 and arranged in two or three tiers. The hot gases then pass through flues in the brickwork below the retort chamber and in so doing heat the secondary air supply flues which latter are arranged to pass up between or near the hot gas flues.

The hot gases are then conveyed in flues direct to the chimney or to the fire- 10 place of a boiler for generating the steam that is to be passed through the retorts. A small further supply of air may be provided at the boiler if required to complete the combustion of the producer gas and the waste gases are finally conveyed to a chimney.

The steam produced in the boiler, which latter may be of any suitable form or 15 construction is by an automatic reducing valve or otherwise admitted through a stop valve to the upper retorts and will then after traversing them enter the next lower retorts and so on if more than two tiers are used, and having been meanwhile deprived wholly or nearly of its oxygen (the latter combining with the iron borings) finally passes off from the bottom retorts in the form of steam saturated 20 hydrogen. The steam may be condensed by passing this saturated gas through a coil of pipe surrounded by air or water. The hydrogen then through a stop valve enters one or more horizontal cylindrical storing vessels. Each vessel by a pipe at the bottom communicates with its water tank placed so high as to give the lowest required pressure of gas when the cylindrical vessel is nearly empty of 25 gas. As the hydrogen gas enters a cylinder the water is driven up into its tank and as the gas is consumed by passing off to the tanning pits the water gradually fills the cylinder again. An automatic pressure regulating valve is used to maintain a uniform pressure of gas. The quantity of gas inside the cylinders is indicated by level of water as shown by water gauge glasses fitted to the 30 cylinders. Pressure gauges are provided in connection with the hydrogen supply pipe to the cylinders.

Dated the Fifteenth day of December 1896.

JENSEN & SON

77 Chancery Lane London W.C. Patent Agents. 35

### COMPLETE SPECIFICATION.

#### **“Improvements in the Production of Hydrogen Gas and in Apparatus therefor.”**

I, REGINALD GEORGE LEVENTHORPE of No. 9 Gloucester Terrace, Hyde Park, in the County of Middlesex, Gentleman, do hereby declare the nature of this 40 invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

The hydrogen gas is produced in the well known manner by passing steam through one or more heated retorts charged with iron borings.

According to my invention I arrange the retorts in a brickwork setting or 45 structure that also comprises a so-called producer. I head the retorts externally by gases produced therein and proceeding therefrom, and I employ the surplus heat of the said gases on their way from the retort chamber to the chimney for

N<sup>o</sup> 28,721.—A.D. 1896.

3

*Improvements in the Production of Hydrogen Gas and in Apparatus therefor.*

the heating of a boiler which supplies the steam required for passing through the retorts.

The steam in passing through the heated retorts separates more or less into oxygen and hydrogen, the former being taken up by the iron borings, while the hydrogen under a pressure derived from that of the steam in the boiler (though usually much wire drawn or lowered) is passed into a gas holder to be stored therein and utilized as required. I may use an ordinary gas holder or gasholders but on the score of economy I prefer to use two storing cylinders placed horizontally side by side. In connection with the gasholder or gasholders I provide one, two, or more water tanks placed at such an elevation as to represent a suitable head or pressure under which the gas is to be supplied to the place of application. A governor may be used to allow the water in the cylinder to run away at the atmospheric pressure if desired. These cylinders each with its tank are intermittently or alternately either in use or being charged. I would here note that an arrangement as herein described is particularly suitable for supplying the liquor in tan pits with hydrogen gas according to the rapid tanning process described in the specification of Bake & Leverett's patent No. 13195 dated 7th. July 1894.

I shall now describe a suitable form of apparatus for carrying out the process described Fig. 1 of the drawings is an elevation and Fig. 2 a plan view of the whole plant, Fig. 3 is a vertical cross section through the producer and the retort chamber arranged side by side in one brickwork setting, fig. 4 a vertical longitudinal section through the producer, fig. 5 a similar section through the retort chamber and fig. 6 a plan. Fig. 7 shows the front end of the retorts, fig. 8 the back end of same. Fig. 9 is a section shewing the joint between a retort and its pipe, fig. 10 a section showing the joint between the end of a retort and its cover and fig. 11 an end view of the retort. Fig. 12 is a side view of an alternative governing device.

The producer furnace A and the retort chamber H are arranged side by side in the same brick structure. The producer furnace narrows towards the bottom see fig. 3, and is arched at the top. It is charged with coke and supplied with a restricted quantity of air from flues *c*<sup>1</sup> *c*<sup>2</sup> through the intakes *c* *c* laterally entering the ash pit C below the grate in such restricted quantity as to produce mainly carbonic oxide, which gas passes off through openings *o*<sup>1</sup> *o*<sup>2</sup> *o*<sup>3</sup> *o*<sup>4</sup> *o*<sup>5</sup> in the arched top into a combustion chamber E where it is converted partially or as desired into carbon dioxide by a secondary and similarly restricted supply of air which is conveyed to the combustion chamber by the flues *h* *h*<sup>1</sup>. These gases from the combustion chamber E are then admitted through the opening *e* to the retort chamber H and being deficient in oxygen will have no injurious action on the retorts R; these are cylindrical and arranged in two tiers (or more). The hot gases then pass through flues *d* in the brickwork below the retort chamber H and in so doing heat the secondary air supply flues *h* which latter are arranged to pass up between (or near) the hot gas flues *d*. The hot gases are then conveyed in a flue M direct to the fire place of the boiler B (figs. 1 and 2) for generating the steam that is to be passed through the retorts R. A small further air supply may be provided at the boiler if required to complete the combustion of the producer gas, and the waste gases are finally conveyed to the chimney. The said further or final air supply may be heated by the waste gases from the retort furnace or the waste gases from the boiler.

The steam produced in the boiler which latter may be of any suitable form or construction is by an ordinary or by an automatically working reducing valve K and pipe *o* fig. 1 admitted through stop valves I fig. 7 to the upper retorts R and will then after traversing them enter the next lower retorts and so on if more than two tiers are used and having been meanwhile deprived wholly or nearly of its oxygen (the latter combining with the iron borings) finally passes off from the bottom retorts by the pipe *v* in the form of hydrogen saturated with steam. The latter may be condensed by passing the saturated gas through a coil of pipe W

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N<sup>o</sup> 28,721.—A.D. 1896.

*Improvements in the Production of Hydrogen Gas and in Apparatus therefor.*

figs. 1 and 2 surrounded by air or water and rises in a pipe above the tanks T for the purpose of preventing water from flowing back into retorts, in case the steam pressure were at any time too low. The hydrogen then through a stop valve enters one or more horizontal storing vessels or gasholders G. Each vessel by a pipe *g* at the bottom communicates with its water tank T placed so high as to give the lowest required pressure of gas when the cylindrical vessel G is nearly empty of gas. As the hydrogen gas enters a vessel G the water is driven up into its tank T, and as the gas is consumed by passing away to the tanning pits or other place of use the water gradually fills the cylinder G again. The gas outlet pipe S from the gasholders G to the outlet main is carried up above the tanks T before passing off through the stop valve S<sup>1</sup>, so that in case of valves being left open no water shall be able to pass into the outlet mains. The quantity of gas inside the cylinder is indicated by level of water as shewn by water gauge glasses fitted to the cylinders G. Pressure gauges are provided in connection with the hydrogen supply pipe to the cylinders. The steam from the boiler may be superheated by passing through a pipe in the brickwork before entering the retorts. 15

L fig. 11 is a small automatic pressure regulating gasholder contained in the tank N which is charged with water. Gas under pressure is conveyed from the gasholders G to this regulating gasholder by the pipe O. The same pressure is thus maintained in the vessels G and L. When the gas pressure rises the bell L lifts and its stem L<sup>1</sup> moves the lever P which by the rod Q and lever Q<sup>1</sup> actuates the water release valve S thus allowing the water to pass out of the vessel G according to the pressure contained therein. L<sup>2</sup> are small weights for adjusting the pressure at which the regulator lifts. The rod Q is adjustable as to length by a right and left hand nut Q<sup>2</sup>. The lever Q<sup>1</sup> has several holes for connecting the rod Q to one of them as required. The water from the vessel G may be allowed to run into the drain or be pumped back into the tank T. 25

Referring to figs. 7 and 8 the pipes connecting the retorts may suitably be thus arranged respectively at the front and back of the retorts. Safety valves are fitted to the upper retorts as shewn or to all the retorts. The joints for connection of the pipes with the retorts should be as shewn in fig. 9 that is to say the end of the weldless steel pipe *p* is as shewn swelled out conically at the end the conical part making joint with the rounded male end of a fitting *q* screwed into the retort, a union nut *r* screwed on this fitting holding the parts together. 35

The retorts have by preference as shewn in figs 9 and 10 end covers V fastened by hinged bolts V<sup>1</sup> and the joints are made by a thin copper strip V<sup>2</sup> which is pressed by a bead on the retort into a corresponding groove turned in the cover. The safety valves and other fittings are on the body of the retort and not on the covers, as the latter have to be frequently removed. The retorts are coated with a thin layer of fire-resisting cement such for instance as the so-called volcanic cement, for protection against oxydation. I do not claim the construction of the retorts nor the means for joining the pipes thereto. 40

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed I declare that what I claim is:— 45

1. The manufacture of hydrogen by passing steam through successive tiers of retorts containing iron borings and which are set in brickwork and adjoin a so-called gas producer the gases from which heat the retorts and then pass off to heat a boiler for producing the aforesaid steam substantially as set forth. 50

2. The combination of the furnace, the combustion chamber over it, the chamber arranged by the side of the furnace, and containing the hydrogen generating retorts, the exit flues from the retort chamber, and the secondary air supply flues heated by the heat from the exit flues substantially as described with reference to figs. 3 to 6. 55

3. The automatic gas pressure regulating gasholder for hydrogen generating 50

N<sup>o</sup> 28,721.—A.D. 1896.

5

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*Improvements in the Production of Hydrogen Gas and in Apparatus therefor.*

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and storing apparatus in combination with the water outlet from the main gas-holder or gasholders, substantially as described with reference to fig. 12.

4. The combination of a hydrogen storing vessel, a water head therefor and trapped gas inlet and outlet pipes substantially as described with reference to 5 figs. 1 and 2.

Dated this Thirteenth day of May 1897.

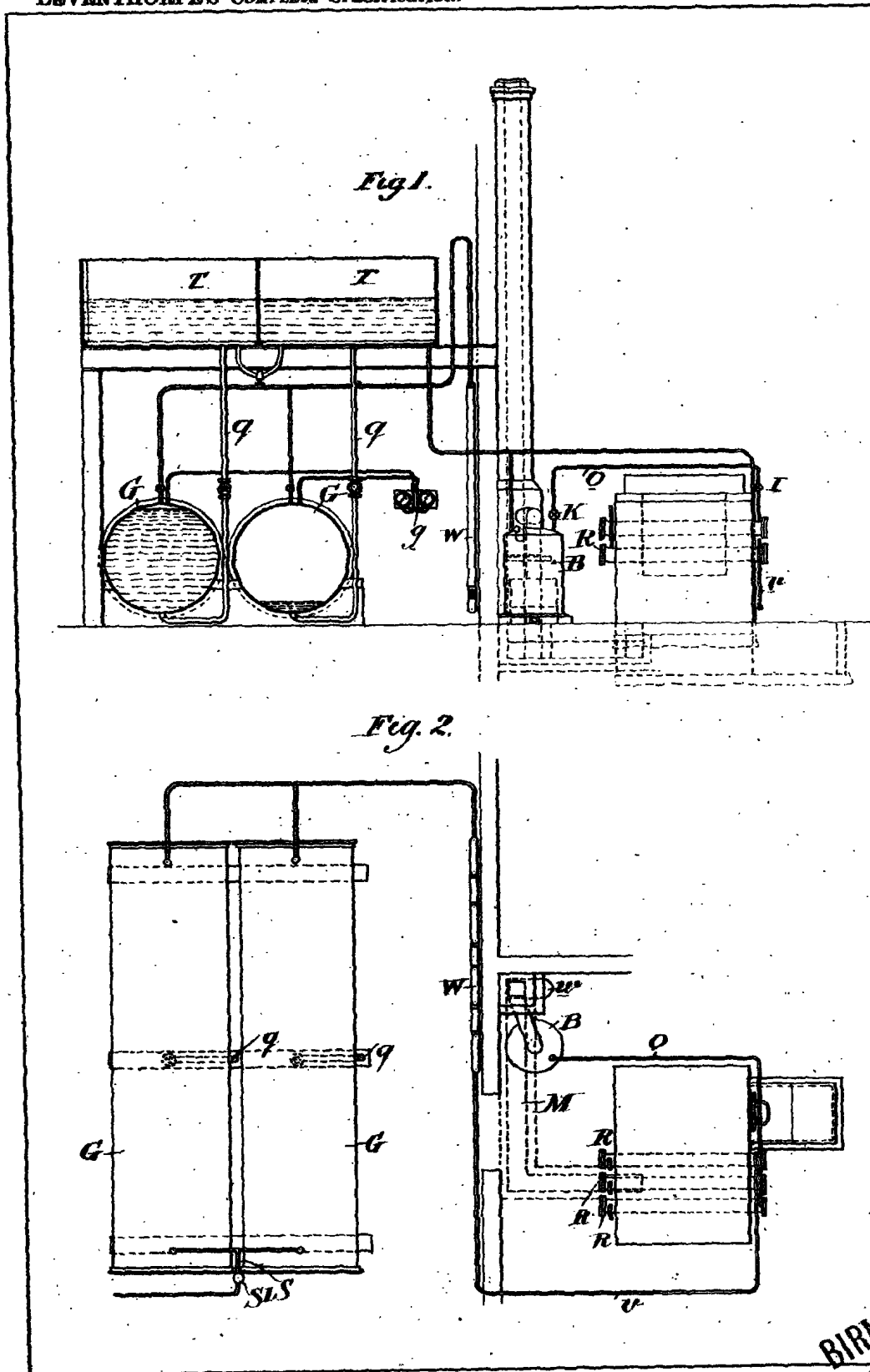
JENSEN & SON  
77 Chancery Lane London W.C. Patent Agents.

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Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1897.

A.D. 1896. Dec. 15. N<sup>o</sup>. 28,731.  
LEVENTHORPE'S COMPLETE SPECIFICATION.

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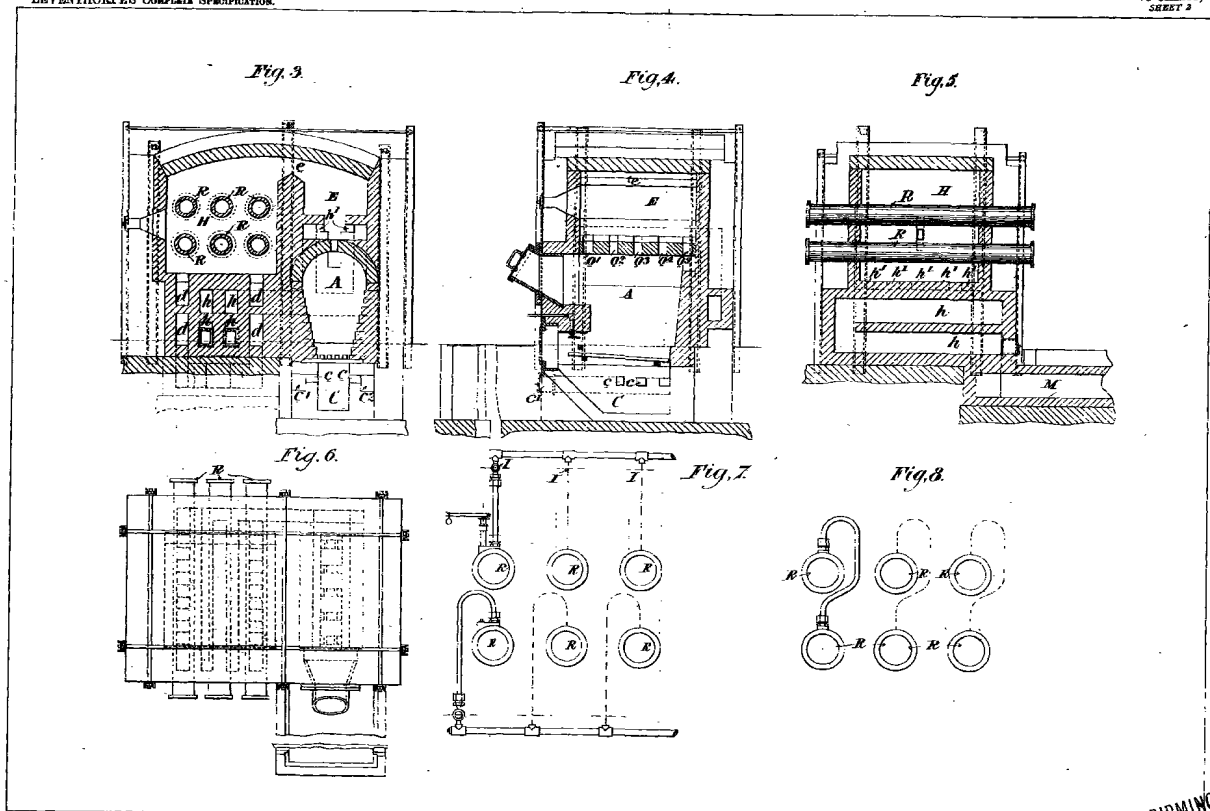


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LEVENTHORPE'S COMPLETE SPECIFICATION.

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SHEET 2



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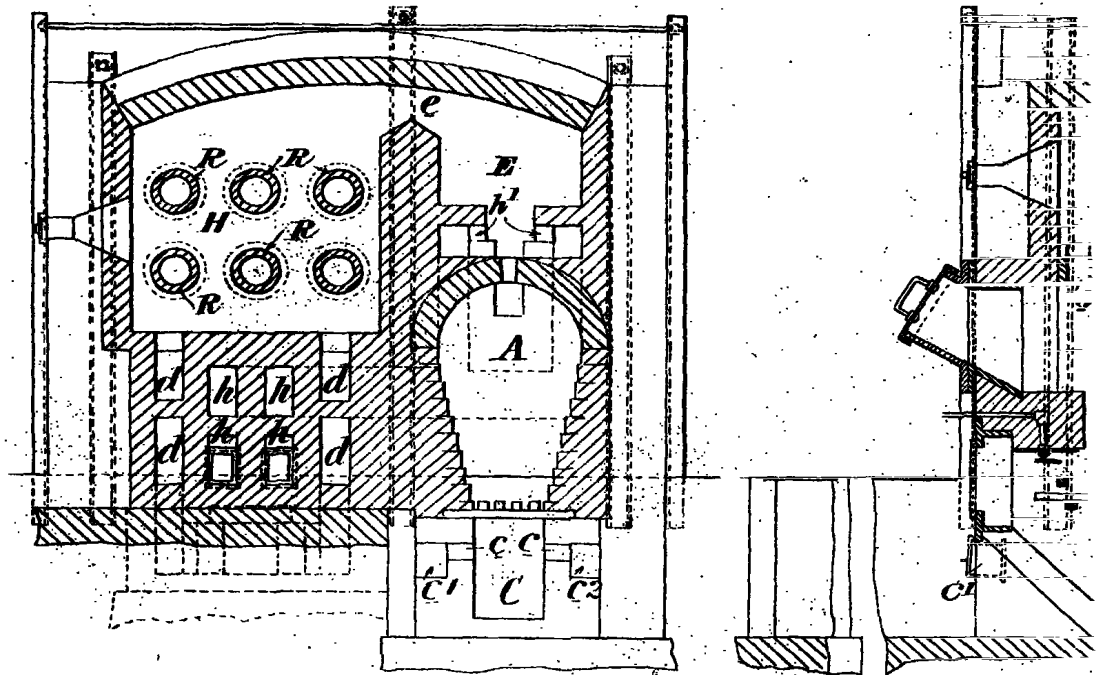
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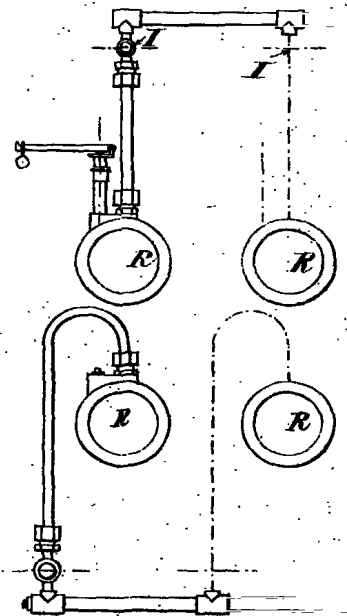
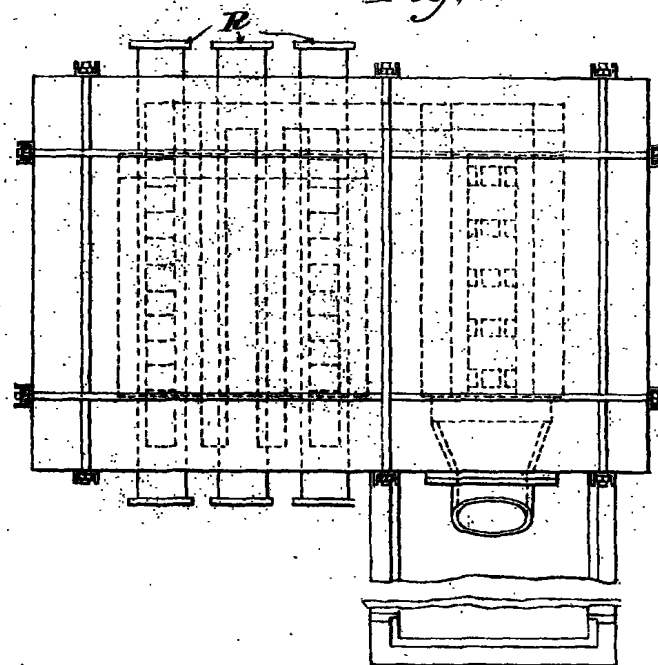
A.D. 1896. DEC. 15. N<sup>o</sup> 28,721.

LEVENTHORPE'S COMPLETE SPECIFICATION.

*Fig. 3.*



*Fig. 6.*



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Fig. 4.

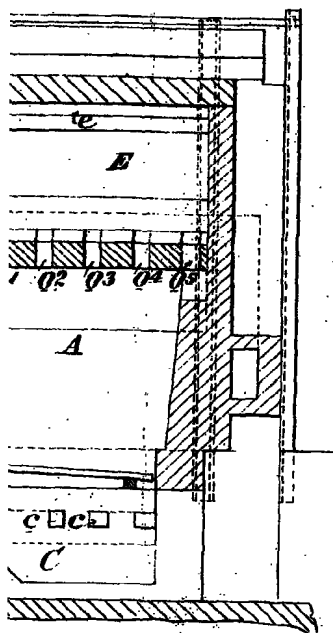


Fig. 5.

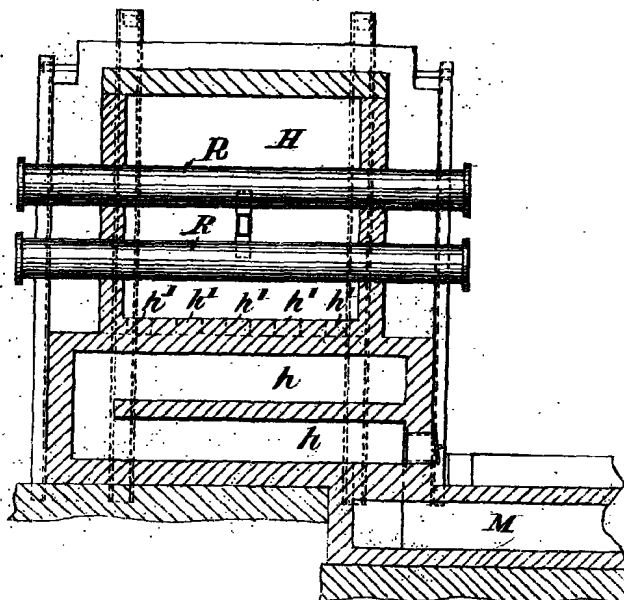


Fig. 7.

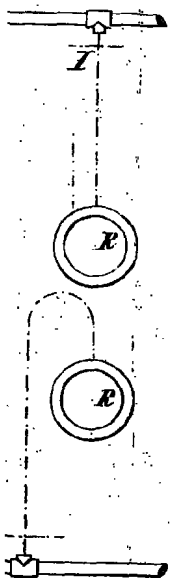
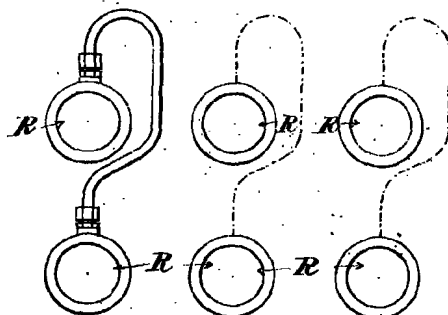


Fig. 8.

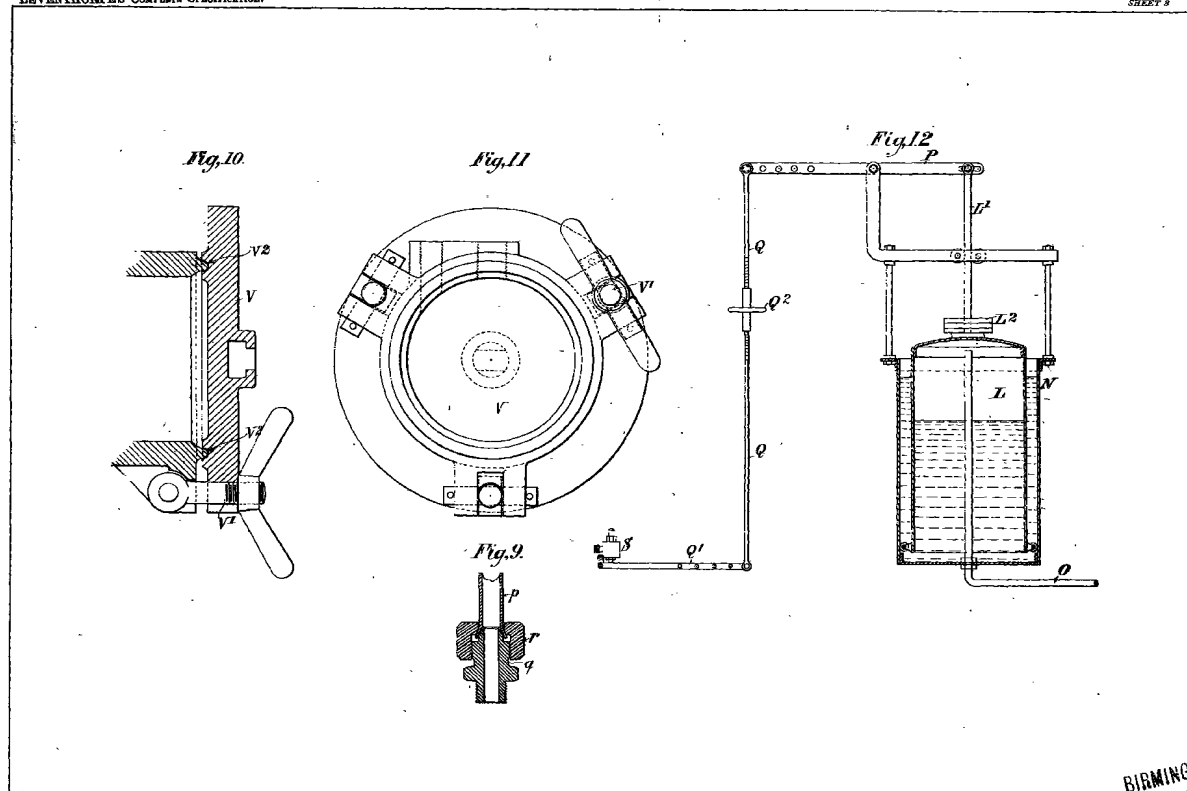


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LEVENTHORPE'S COMPLETE SPECIFICATION.

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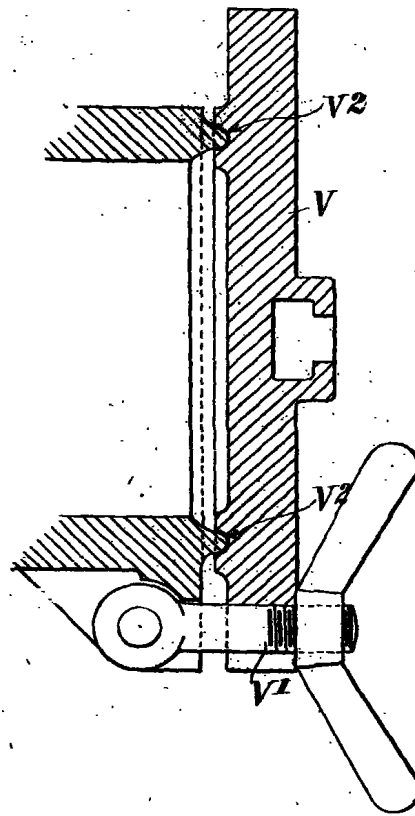


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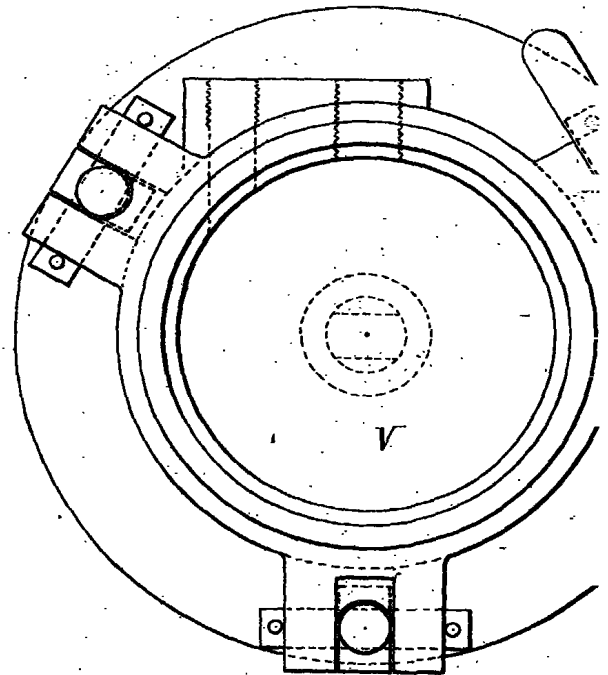
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LEVENTHORPE'S COMPLETE SPECIFICATION.

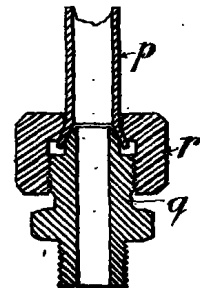
*Fig. 10.*



*Fig. 11.*

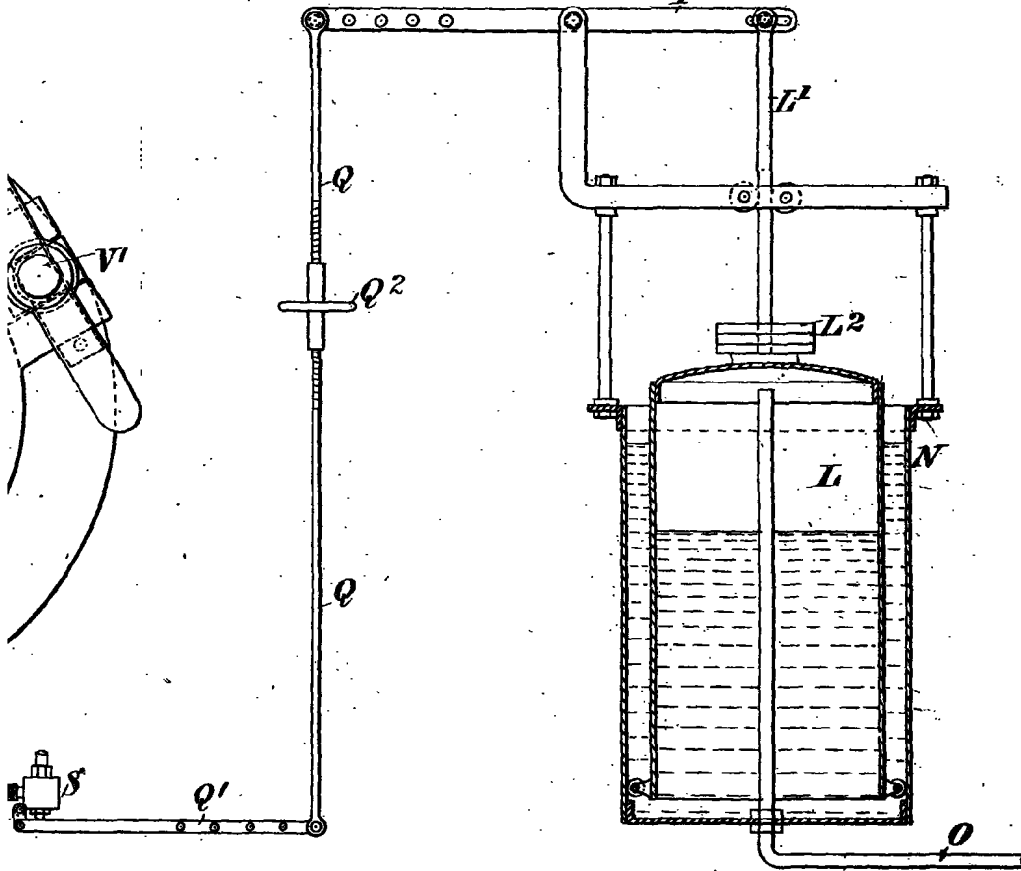


*Fig. 9.*



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SHEET 3.

Fig. 12  
P



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N<sup>o</sup> 11,163

A.D. 1897

*Date of Application, 5th May., 1897**Complete Specification Left, 30th Oct., 1897—Accepted, 18th Dec., 1897*

## PROVISIONAL SPECIFICATION.

**Improvements in Oxy-hydrogen Jets for Lime Light, and other Purposes.**

I WALTER JOSEPH COLES of 117 East Dulwich Grove in the County of Surrey, Engineer do hereby declare the nature of this invention to be as follows:—

The object of my invention is so to construct the jet, that it can be used, without alteration, with the two gases at the same or at different pressures; and also to obtain  
5 a greater illuminating power.

To effect this, the jet, according to my invention is provided with a chamber having a central circular passage, surrounded by an annular passage, the size of which may or may not be adjustable. The gas of the higher pressure as it issues from this annular passage carries with it the other gas as it comes through the central passage,  
10 thence through the mixing chamber along the tube as in the ordinary jet to the nipple where the combustion takes place.

The action with gases of equal pressures is exactly similar.

The mixing chamber may be dispensed with in some cases.

Dated this third day of May 1897.

15

W. J. COLES

## COMPLETE SPECIFICATION.

**Improvements in Oxy-hydrogen Jets for Lime Light and other Purposes.**

I, WALTER JOSEPH COLES of 117 East Dulwich Grove in the County of Surrey, Engineer do hereby declare the nature of my invention for Improvements in oxy  
20 hydrogen jets and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

My invention relates to improvements in oxy-hydrogen jets, by means of which great power of heating, and consequently of light may be obtained, even if one of the gases is at a very low pressure; the jet being constructed in such a manner that  
25 it may be used, without alteration, with gases of the same, or different pressures and also that the usual mixing chamber may be dispensed with.

In order that the invention may be more readily understood I have illustrated it in the accompanying drawing forming a part of this specification, of which the following is the description.

30 Fig 1 is a side elevation and Fig 2 is a plan in section.

The same letters indicate the same parts in both figures.

One of the two gases (the one of higher pressure if there is any difference) entering by passage A and issuing through narrow annular space B at a high velocity induces

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N<sup>o</sup> 11,163.—A.D. 1897.

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*Cole's Improvements in Oxy-hydrogen Jets for Lime Light and other Purposes.*

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a more rapid current of gas through the central jet D, the gases mix and pass along through C thence by pipe F to nipple G at which they are ignited.

The passage C may be formed in a separate piece in such a manner that it can be moved backward or forward thus altering area of annular space B, the movement being controlled by an eccentric screw E or other suitable means. By this 5 arrangement the quantity of gas coming in by passage A can be regulated so as to bear the correct proportion to the gas coming through central jet D.

The mixture of the gases brought about by this arrangement is so perfect that the usual mixing chamber may be omitted, but if desired this may be inserted at any point between passage C and the nipple G. 10

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:

1st The combination of central jet and passages as herein set forth and described for oxy hydrogen jets. 15

2nd The arrangement of adjusting by eccentric screw or other suitable means together with sliding passage as herein described.

3rd The general combination herein described and shown in the drawings.

4th The combination herein set forth with a mixing chamber as stated.

Dated this 30th day of October 1897.

WALTER JOSEPH COLES. 20

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Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1898.

A.D. 1897. MAY 5. N<sup>o</sup> 11,163.  
COLES' COMPLETE SPECIFICATION.

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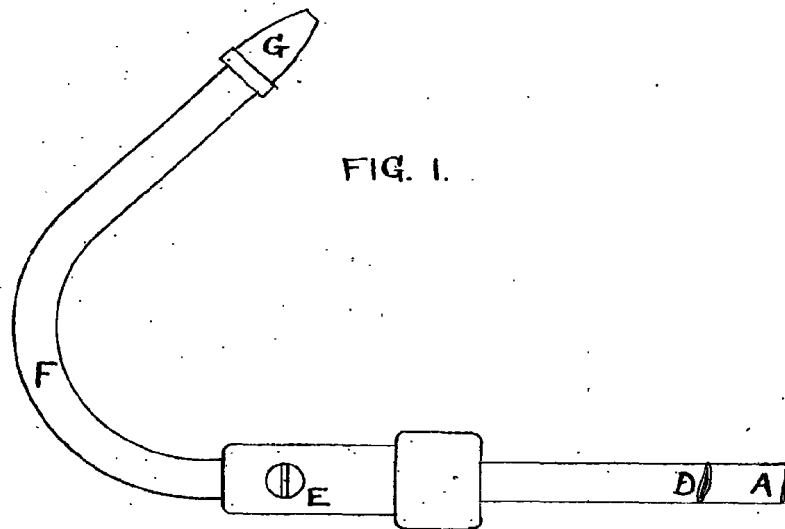


FIG. 1.

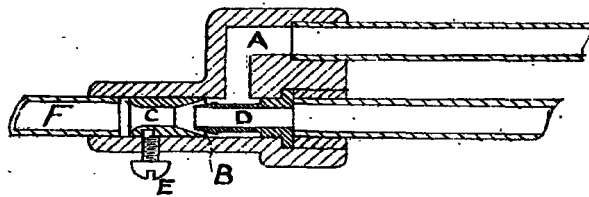


FIG. 2.

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N<sup>o</sup> 14,397

A.D. 1897

*Date of Application, 14th June, 1897**Complete Specification Left, 7th Mar., 1898—Accepted, 20th May, 1898***PROVISIONAL SPECIFICATION.****Improvements in the Generation and Utilization of Hydrogen Gas and Electricity for Motive Power Lighting and Heating purposes.**

I, LUTHER HENRY WATTLES, of No. 122, Roger Williams Avenue, Providence, Rhode Island, United States of America, Machinist, do hereby declare the nature of this invention to be as follows:—

- This invention relates to improvements in systems of generating and using hydrogen gas and electricity; and it consists in providing a generator or a number of generators in which hydrogen gas and electricity are both generated simultaneously, combining therein gas-collecting apparatus having ducts for conducting the gas to the apparatus or mechanism intended for its storage or use, with conductors for the electricity generated therein to deliver it to the apparatus intended for its use, and in combining the gas using apparatus and the electrical apparatus with a common means of receiving the energy developed by the conversion of the gas and electricity into mechanical power, so that the two forms of energy developed in the generator thus become collected, converted, and delivered at the same time to the same mechanism for its utilization or work.
- The object of my invention is to provide a generator of hydrogen gas and electricity and to combine with the same such a combination of apparatus and mechanism capable of converting them into the form of useful work as will secure by said means the maximum availability and use of the forces developed in the generator.
- I employ a cup or cell, made of copper, to which a cover is fitted, by means of an internal screw thread to a corresponding external screw thread upon the neck of the cup. A packing is fitted around the neck of the cup so as to make a tight joint between the cup and the cover when the latter is screwed on in position thereon. The cover has two apertures through which the holder projects and upon which the electrode is mounted when in position within the cup. The electrode or zinc has a central opening through which the threaded extremity of the holder passes, and by means of the nut the zinc and the holder are thereby securely connected together. The lower portion of the aperture is enlarged and squared to fit a correspondingly shaped portion of the holder to prevent the zinc from turning upon the holder through accident or otherwise. The cover is provided with sleeves having insulation bushings by means of which the holder and the cover may be insulated from each other. Each of the necks of the holder is provided with a spring retaining catch which is fitted in a groove therein and by means of which the holder will be held in an elevated position by resting upon the bushings whenever it is desired to lift the zinc out of the solution in the cup and hold it in that position. The sleeves in the cover retain the holder with the zinc in a central position in the cup in case the latter should be tilted or the like. The holder is provided with an insulating covering to prevent short circuiting in the cup or with it.
- Within the cup an inverted gas collector of copper or other metal is arranged and secured to the cover. The collector is of larger dimensions than the zinc in

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that portion of it within which the zinc is suspended so that no contact is made between the two parts of the device but is narrowed in its dimensions in its upper portion and is provided with an aperture which also extends through the cover and through a gas conductor having nipples to which conducting tubes or pipes for conveying the gas generated within the collector may be connected. The cover 5 which together with the entire shell of the cup forms one of the electrodes of the generator or battery is provided with a binding post having a nut to which the wire conductor for the current generated may be connected. The holder has upon its upper extremities a corresponding pair of binding posts and nuts for the other conductor to be connected with. The cover is also provided with an opening to 10 which a stopper is fitted for the purpose of filling the cup with the solution required, renewing or decanting it, or the like.

The solution required to generate the gas consists of water and sulphuric acid or any other acid that will liberate hydrogen gas and generate electric currents by its chemical action upon zinc iron or other substance capable of such effects. The 15 strength of the solution is determined by the rapidity with which the gas and electricity are to be produced and may be varied from, say, one part (in bulk) to twenty parts of water up to one part acid to four parts water or even stronger than this when quick action is necessary. The production of hydrogen gas and electricity by the chemical action of dilute sulphuric acid upon zinc being well known 20 and understood its further description is deemed unnecessary. My generator being thus described I will now explain the manner of its use in combination with the other mechanism required to carry out the purposes of my invention.

In one form of my arrangement I employ a series or battery of generators made as already described. The cups and zincs are connected alternately in series like 25 any battery of galvanic cells connected up to produce a maximum voltage; but the generators may be also connected in multiple arc if quantity rather than voltage is required; or modifications of both of these methods of connecting up the poles of a number of cells may be employed, if preferred. The terminal elements of the battery are connected with the conducting wires respectively, which 30 connect in turn with the terminals of an electric motor and to which the current generated as described is conducted and in which it is converted into mechanical power by the motor in the well known manner of electric motors. The circuit conductors leading to the motor have the usual fuse switch and resistance box by means of which the current to the motor can be controlled. Each one of 35 the gas conductors leading from the gas collectors of the generators is connected by means of nipples and couplings which are made of any suitable insulating substance not subject to destructive effects of the gas, so as to make one continuous conduit for the gas evolved by the whole series of cups that may be in active operation producing the gas at the time. The gas is conducted by a main duct to a gas 40 engine one end of the duct being connected with a conductor at the end of the series of cells and the other end with the gas engine for this purpose. A branch duct leads to a pump and gas holder. Another branch pipe leads to a retort or carburetter. A further pipe has a connection with the gas holder and another with the carburetter, another with the gas burner, and finally one which connects it 45 again with the main duct. Valves or cocks are fitted in the gas ducts around in the different positions necessary for the proper control of the flow and manipulation of the gas as required.

The gas engine receives its supply of gas through a suitable pipe the flow being regulated by a valve. A bevelled gear mechanism actuates the valve mechanism 50 of the engine.

The conducting wires referred to are provided with switches having terminal connections with conductors in which the induction coil is in circuit. There are further conductors which have terminals at the engine and connections with the coil by which a circuit between it and the engine is established whenever the 55 electrodes within the cylinder are in contact. The piston, to which one of the electrodes is attached carries the latter away from the other electrode with every

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outward stroke of its operation, thereby breaking contact with the last electrode and producing an electric spark within the gas contained in the cylinder and igniting it at a right time, so as to cause the proper explosive effect necessary in operating gas-engines.

- 5 The power of the engine is applied, through its connecting rod, to the crank shaft in the usual manner. The power of the motor may be applied to the crank shaft of the engine through a belt and wheel of the engine, in which case the engine crank shaft becomes the common receiver of power produced by the motor and the engine.
  - 10 A work shaft may be provided having a pulley over which a belt runs and is driven by a pulley on the engine shaft. The work shaft has also a pulley to which a belt from the motor may be directly connected. By this arrangement the shaft becomes the receiver of power produced by the engine and the motor and from which it could be transmitted otherwise for application or use.
  - 15 Switches in the conducting wires have terminal connections with certain circuit wires in which an electric lamp is placed and by means of which the electric current from the generators may be caused to produce light. Switches are also placed in connection with the same conducting wires and having terminal connections with a loop in which a resistance or heating coil is placed in circuit, so that the electric
  - 20 current may be utilized for heating purposes, if desired.
- The operation of my invention will now be described: The generators are prepared for use by charging each one of them with a solution of acid of the requisite strength and filling each one to a level so that all of the zinc except its shank or neck becomes immersed therein and subject to the dissolving and chemical effects
- 25 of the solution. The circuit between the zinc and the cup is closed. The cap or cover being adjusted upon the cup and the stopper being in place each generator becomes ready for effective use.

- The gas connections between each of the generators and the external gas receiving and converting apparatus being in proper connection and condition, the gas
- 30 becomes evolved in each generator and passes through the collectors through the ducts and through the engine, where it is used, as produced, in producing mechanical effect, as already described, or it may be delivered into the holder and stored there until required for use; or it may be passed through the carburetter and enriched, as already described, by the addition of carbon or hydrocarbon gases
  - 35 and afterward used in the engine or for illuminating or other purposes, as desired.

- The electric current, which becomes generated simultaneously with the evolution of the gas and the disintegration of the zinc, is converted by the motor into mechanical power, which may be applied to the crank shaft of the engine or the independent work shaft, as already explained. It can thus be seen that the two
- 40 forms of energy simultaneously generated in the generators are at the same time transmitted to the corresponding mechanisms for converting them into mechanical energy, and in this way the maximum efficiency for useful work is delivered to the work shaft intended for its reception and use. It can also be observed that the electric current from the generator also co-operates through the agency of the
  - 45 induction coil with the gas in igniting the latter in the engine, and thus effects the successful operation of the engine.

- The importance of this invention may be understood from the fact that for some purposes primary batteries used for generating electric currents alone are near the point, as to economy, of successful competition with other methods of generating
- 50 and using electricity. Now by the additional useful efficiency obtained by this method of using the gas as generated simultaneously and in conjunction with the electricity produced it can be seen that it makes it possible for applications of this system of producing and using power in many ways and under conditions never successful commercially heretofore. Its use therefore is in the case of small units
  - 55 of application peculiarly well adapted as a means of propulsion for bicycles, tricycles, motorcycles, or horseless vehicles and other forms of carriages, cars, and devices for transportation.

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The invention is likewise applicable to the propulsion of boats, stationary power installations, small or large, as may be required. Large installations of generators for the production and use of hydrogen gas and electricity can likewise be made and the gas used for general lighting and heating purposes as well and stored in large holders and carbureted as commercial illuminating gas is now treated. The electricity can from the same plant be used for heating, lighting, and power purposes, as now done, in addition to or independent of the combination of the engine and motor mechanism. 5

I am aware that it has been proposed to generate oxygen and hydrogen gases in a battery from the decomposition of water and to use the electricity generated to also assist in the generation of the two gases within the battery in the well known way of decomposing water by the electric current and then conducting the two gases to separate reservoirs, where they were to be accumulated and confined until a pressure of several atmospheres was obtained, and the gases then conducted to separate engines, where they were to be used expansively, like steam or compressed air, and then to be returned again to the battery by suitable mechanism devised for the purpose and then to be used over and over again, as before. 10 15

Dated this 14th day of June 1897.

PHILIP M. JUSTICE,  
Chartered Patent Agent, London, for the Applicant. 20

## COMPLETE SPECIFICATION.

**Improvements in the Generation and Utilization of Hydrogen Gas and Electricity for Motive Power Lighting and Heating purposes.**

I, LUTHER HENRY WATTLES, of No. 122, Roger Williams Avenue, Providence, Rhode Island, United States of America, Machinist, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:— 25

This invention relates to improvements in systems of generating and using hydrogen gas and electricity; and it consists in providing a generator or a number of generators in which hydrogen gas and electricity are both generated simultaneously, combining therein gas-collecting apparatus having ducts for conducting the gas to the apparatus or mechanism intended for its storage or use, with conductors for the electricity generated therein to deliver it to the apparatus intended for its use, and in combining the gas-using apparatus and the electrical apparatus with a common means of receiving the energy developed by the conversion of the gas and electricity into mechanical power, so that the two forms of energy developed in the generator thus become collected, converted, and delivered at the same time to the same mechanism for its utilization or work. 30 35

The object of my invention is to provide a generator of hydrogen gas and electricity and to combine with the same such a combination of apparatus and mechanism capable of converting them into the form of useful work as will secure by said means the maximum availability and use of the forces developed in the generator. 40

The character and purposes of my invention will be more fully explained and understood by reference to what follows herein and as will be pointed out in the claims, and also by reference to the accompanying drawings, in which— 45

Fig. 1 represents a front view of the generator. Fig. 2 represents a vertical section of the same. Fig. 3 is a top or plan view of the generator. Fig. 4 is a top view of the zinc or other element employed for the generation of the gas and

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electric current. Fig. 5 is a side elevation of Fig. 4. Fig. 6 is a bottom view of Fig. 4. Fig. 7 is a front elevation of the holder and terminal for the zinc or other electrode. Fig. 8 is a side elevation of Fig. 7. Fig. 9 represents a diagram of a battery of generators having gas and electrical conductors combined therewith, a gas-engine connected with the gas-conductors, and an electric motor connected with the electric conductors and the engine and the motor both applying their power to the same work-shaft. This figure also shows how the gas may be conveyed or forced into a suitable holder adapted for its storage, if desired, and it also shows how the gas can be connected with a carbureter if it is desired to enrich it by the addition therewith of hydrocarbons or hydrocarbon gas for illuminating purposes or in transit to the engine. It also shows how the electric current can be utilized for electric lighting or heating purposes. The figure further shows how the electric spark which is required for igniting the gas in the engine is obtained by the induction coil necessary for the purpose and the electrical connections of the same with the generator and the engine.

In the drawings, A represents a cup or cell, made of copper, to which a cover A<sup>1</sup> is fitted, by means of an internal screw thread A<sup>2</sup> to the corresponding external screw-thread A<sup>3</sup> upon the neck A<sup>4</sup> of the cup A. A packing A<sup>5</sup> is fitted around the neck of the cup, so as to make a tight joint between the cup and the cover when the latter is screwed on in position thereon.

The cover A<sup>1</sup> has two apertures A<sup>6</sup> A<sup>6</sup>, through which the holder B projects and upon which the electrode C is mounted when in position within the cup A. The electrode or zinc C has a central opening C<sup>1</sup>, through which the threaded extremity B<sup>1</sup> of the holder B passes, and by means of the nut B<sup>2</sup> the zinc C and the holder B are thereby securely connected together. The lower portion of the aperture C<sup>1</sup> is enlarged and squared, as seen at C<sup>2</sup>, to fit a correspondingly shaped portion B<sup>3</sup> of the holder B to prevent the zinc C from turning upon the holder B through accident or otherwise. The cover A<sup>1</sup> is provided with sleeves A<sup>7</sup> A<sup>7</sup>, having insulation bushings A<sup>8</sup> A<sup>8</sup>, by means of which the holder B and the cover A<sup>1</sup> may be insulated from each other. Each of the necks B<sup>4</sup> B<sup>4</sup> of the holder B is provided with a spring retaining catch B<sup>5</sup>, which is fitted in a groove B<sup>9</sup> therein and by means of which the holder will be held in an elevated position, as indicated by the dotted lines in Fig. 2, by resting upon the bushings A<sup>8</sup> A<sup>8</sup> whenever it is desired to lift the zinc out of the solution in the cup and hold it in that position. The sleeves A<sup>7</sup> A<sup>7</sup> in the cover A<sup>1</sup> retain the holder B with the zinc C in a central position in the cup in case the latter should be tilted or the like. The holder B is provided with an insulating covering B<sup>8</sup> to prevent short-circuiting in the cup or with it.

Within the cup A an inverted gas collector D, of copper or other metal, is arranged and secured to the cover A<sup>1</sup>. The collector D is of larger dimensions than the zinc C in that portion of it within which the zinc is suspended, so that no contact is made between the two parts of the device, but is narrowed in its dimensions in its upper portion D<sup>1</sup> and is provided with an aperture D<sup>2</sup>, which also extends through the cover A<sup>1</sup> and through a gas conductor A<sup>9</sup>, having nipples A<sup>10</sup> A<sup>10</sup>, to which conducting tubes or pipes for conveying the gas generated within the collector may be connected. The cover A<sup>1</sup>, which, together with the entire shell of the cup A, forms one of the electrodes of the generator or battery, is provided with a binding post A<sup>11</sup>, having a nut A<sup>12</sup>, to which the wire conductor for the current generated may be connected. The holder B has upon its upper extremities a corresponding pair of binding posts B<sup>6</sup> B<sup>6</sup> and nuts B<sup>7</sup> B<sup>7</sup> for the other conductor to be connected with. The cover A<sup>1</sup> is also provided with an opening A<sup>13</sup>, to which a stopper A<sup>14</sup> is fitted for the purpose of filling the cup with the solution required, renewing or decanting it, or the like.

The solution required to generate the gas consists of water and sulphuric acid or any other acid that will liberate hydrogen gas and generate electric currents by its chemical action upon zinc, iron, or other substance capable of such effects. The strength of the solution is determined by the rapidity with which the gas and

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electricity are to be produced and may be varied from, say, one part (in bulk) to twenty parts of water up to one part acid to four parts water or even stronger than this when quick action is necessary. The production of hydrogen gas and electricity by the chemical action of dilute sulphuric acid upon zinc being well known and understood its further description is deemed unnecessary. My generator being thus described I will now explain the manner of its use in combination with the other mechanism required to carry out the purposes of my invention.

Referring to Fig. 9 A A A represent a series or battery of generators made as already described. The cups and zincs are connected alternately in series like any battery of galvanic cells connected up to produce a maximum voltage; but the generators may be also connected in multiple arc if quantity rather than voltage is required; or modifications of both of these methods of connecting up the poles of a number of cells may be employed, if preferred. The terminal elements A<sup>11</sup> C<sup>11</sup> of the battery are connected with the conducting wires E F, respectively, which connect in turn with the terminals G G<sup>1</sup> of an electric motor G<sup>2</sup> and to which the current generated as described is conducted and in which it is converted into mechanical power by the motor in the well known manner of electric motors. The circuit conductors E F, leading to the motor G<sup>2</sup>, have the usual fuse H, switch I, and resistance box J, by means of which the current to the motor can be controlled. Each one of the gas conductors A<sup>9</sup> A<sup>9</sup>, leading from the gas collectors D D of the generators A A, is connected by means of its respective nipples A<sup>10</sup> A<sup>10</sup> and couplings K K, which are made of any suitable insulating substance not subject to destructive effects of the gas, so as to make one continuous conduit for the gas evolved by the whole series of cups that may be in active operation producing the gas at the time. The gas is conducted by the main duct L to the gas engine M, one end L<sup>1</sup> of the duct being connected with the conductor A<sup>15</sup> at the end of the series of cells A A A and the other end L<sup>2</sup> with the gas engine M for this purpose. A branch duct L<sup>3</sup> leads to a pump N and gas holder O. Another branch pipe L<sup>4</sup> leads to a retort or carbureter P. The pipe L<sup>5</sup> has a connection L<sup>6</sup> with the gas holder O and another L<sup>7</sup>, with the carbureter P, another L<sup>8</sup> with the gas burner Q, and, finally, one L<sup>9</sup>, which connects it again with the main duct L. Valves or cocks R R R are fitted in the gas ducts around in the different positions necessary for the proper control of the flow and manipulation of the gas as required.

The gas engine M receives its supply of gas through the pipe L<sup>10</sup>, the flow of which is regulated by the valve R<sup>1</sup>. M<sup>6</sup> represents a beveled gear mechanism which actuates the valve mechanism (not shown) of the engine M.

The conductors E F are provided with switches S S<sup>1</sup>, having terminal connections with the conductors E<sup>1</sup> F<sup>1</sup>, in which the induction coil T is in circuit. The conductors T<sup>1</sup> T<sup>2</sup> have terminals T<sup>3</sup> T<sup>4</sup> at the engine M and connections with the coil T, by which a circuit between it and the engine M is established whenever the electrodes T<sup>5</sup> T<sup>6</sup> within the cylinder are in contact. The piston M<sup>1</sup>, to which the electrode T<sup>6</sup> is attached, carries the latter away from the electrode T<sup>5</sup> with every outward stroke of its operation, thereby breaking contact with the electrode T<sup>5</sup> and producing an electric spark within the gas contained in the cylinder and igniting it at a right time, so as to cause the proper explosive effect necessary in operating gas engines.

The power of the engine M is applied, through its connecting rod M<sup>2</sup>, to the crank shaft M<sup>3</sup> in the usual manner. The power of the motor G<sup>2</sup> may be applied to the crank shaft M<sup>3</sup> of the engine M through the belt U and wheel M<sup>4</sup> of the engine M, in which case the engine crank shaft becomes the common receiver of power produced by the motor and the engine.

A work shaft V may be provided having a pulley V<sup>1</sup>, over which the belt W runs and is driven by a pulley M<sup>5</sup> on the engine shaft M<sup>3</sup>. The shaft V has also a pulley V<sup>2</sup>, to which the belt U from the motor G<sup>2</sup> may be directly connected, as shown by the dotted lines, if preferred. By this arrangement the shaft V becomes the receiver of power produced by the engine and the motor and from which it could be transmitted otherwise for application or use.

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Switches  $S^2 S^3$  in the conductors  $E F$  have terminal connections with the circuit wires  $X X^1$ , in which the electric lamp  $X^2$  is placed and by means of which the electric current from the generators may be caused to produce light. Switches  $S^4 S^5$  are also placed in connection with the conductors  $E F$  and having terminal connections with the loop  $Y Y^1$ , in which the resistance or heating coil  $Y^2$  is placed in circuit, so that the electric current may be utilized for heating purposes, if desired.

The operation of my invention will now be described: The generators are prepared for use by charging each one of them with a solution of acid of the requisite strength and filling each one to the level indicated by the dotted line  $a b$  in Fig. 2, in which case all of the zinc  $C$  except its shank or neck becomes immersed therein and subject to the dissolving and chemical effects of the solution. The circuit between the zinc  $C$  and the cup  $A$  is closed, as indicated by the circuit established through the conductors  $E F$  and mechanism connected therewith in Fig. 9. The cap or cover  $A^1$  being adjusted upon the cup and the stopper  $A^{14}$  being in place each generator becomes ready for effective use.

The gas connections between each of the generators and the external gas receiving and converting apparatus being in proper connection and condition, the gas becomes evolved in each generator and passes through the collectors through the ducts and through the engine, where it is used, as produced, in producing mechanical effect, as already described, or it may be delivered into the holder  $O$  and stored there until required for use, or it may be passed through the carbureter  $P$  and enriched, as already described, by the addition of hydrocarbons or hydrocarbon gases and afterward used in the engine or for illuminating or other purposes, as desired.

The electric current, which becomes generated simultaneously with the evolution of the gas and the disintegration of the zinc, is converted by the motor into mechanical power, which may be applied to the crank shaft of the engine or the independent workshaft, as already explained. It can thus be seen that the two forms of energy simultaneously generated in the generators are at the same time transmitted to the corresponding mechanisms for converting them into mechanical energy, and in this way the maximum efficiency for useful work is delivered to the workshaft intended for its reception and use. It can also be observed that the electric current from the generator also co-operates through the agency of the induction coil with the gas in igniting the latter in the engine, and thus effects the successful operation of the engine.

The importance of this invention may be understood from the fact that for some purposes primary batteries used for generating electric currents alone are near the point, as to economy, of successful competition with other methods of generating and using electricity. Now by the additional useful efficiency obtained by this method of using the gas as generated simultaneously and in conjunction with the electricity produced it can be seen that it makes it possible for applications of this system of producing and using power in many ways and under conditions never successful commercially heretofore. Its use therefore is in the case of small units of application peculiarly well adapted as a means of propulsion for bicycles, tricycles, motorcycles, or horseless vehicles and other forms of carriages, cars and devices for transportation.

The invention is likewise applicable to the propulsion of boats, stationary power installations, small or large, as may be required. Large installations of generators for the production and use of hydrogen gas and electricity can likewise be made and the gas used for general lighting and heating purposes as well and stored in large holders and carbureted as commercial illuminating gas is now treated. The electricity can from the same plant be used for heating, lighting, and power purposes, as now done, in addition to or independent of the combination of the engine and motor mechanism herein shown and described as in combination.

I am aware that it has been proposed to generate oxygen and hydrogen gases in a battery from the decomposition of water and to use the electricity generated to also assist in the generation of the two gases within the battery in the well-

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known way decomposing water by the electric current and then conducting the two gases to separate reservoirs, where they were to be accumulated and confined until a pressure of several atmospheres was obtained, and the gases then conducted to separate engines, where they were to be used expansively, like steam or compressed air, and then to be returned again to the battery by suitable mechanism devised 5 for the purpose and then to be used over and over again, as before. Now I do not claim such a system of gas generation or utilization, and my system is unlike it, as I conduct the electricity outside of the generator and utilize it directly in running a modern dynamic electric motor if for power purposes or apply it directly to an electric lamp or heater if for lighting or heating purposes. I use the electricity 10 external to the battery and not within it. Then the gas is used explosively in the gas engine and by its ignition and not merely by its expansion from an artificial compression, as compressed air is used in an air engine. I also use the gas and electricity in the same engine and cylinder mechanism, and I couple a modern electric motor and a common gas engine directly or indirectly to the same work- 15 shaft, and thus generate the two forms of energy in the same generator and utilize them in the same mechanism for conversion.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:— 20

1. In combination with a generator, or series of generators of hydrogen gas and electricity, the electric conductors connected with the electrodes of the generator or generators, the electric-dynamo motor mechanism connected with the electric conductors, a gas duct connected with the gas collector or collectors of the generator or generators, a gas engine having connection with the gas-duct and adapted 25 to be operated by the gas from said generator or generators, and the mechanisms of the engine and motor for the delivery of the mechanical power produced by the engine and motor, being connected to the same shaft or means of utilization, substantially as specified.

2. In combination with a generator, or series of generators of hydrogen gas and electricity, an electric-dynamo motor mechanism connected with the electric 30 generating devices of the generator, a gas engine mechanism connected with the gas generating apparatus of the generator and the power-delivery mechanisms of the electric motor and the gas engine being connected to the same power receiving apparatus, substantially as specified. 35

Dated this 5th day of March 1898.

PHILIP M. JUSTICE,  
Chartered Patent Agent, London, for the Applicant.

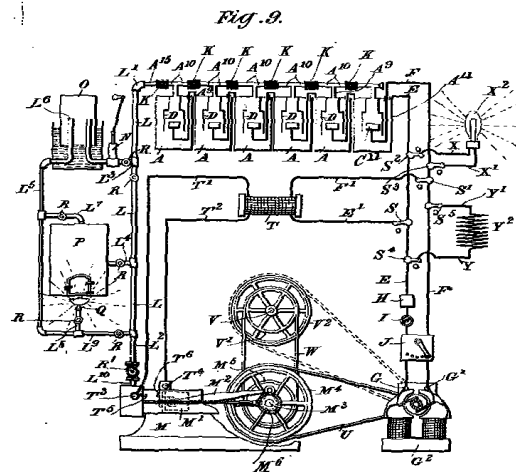
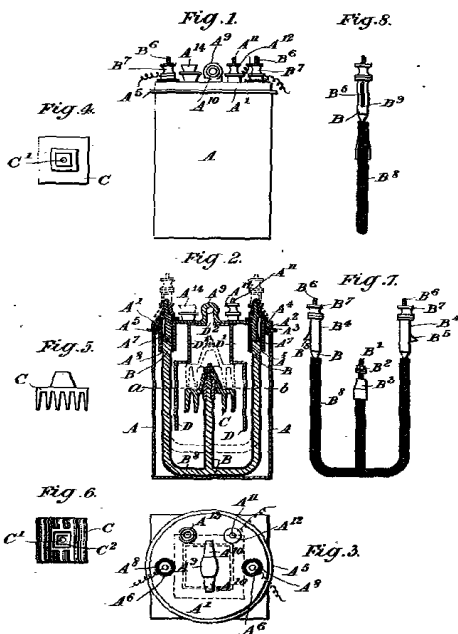
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WATTLER'S COMPLETE SPECIFICATION.

SHEET 1

SHEET 2



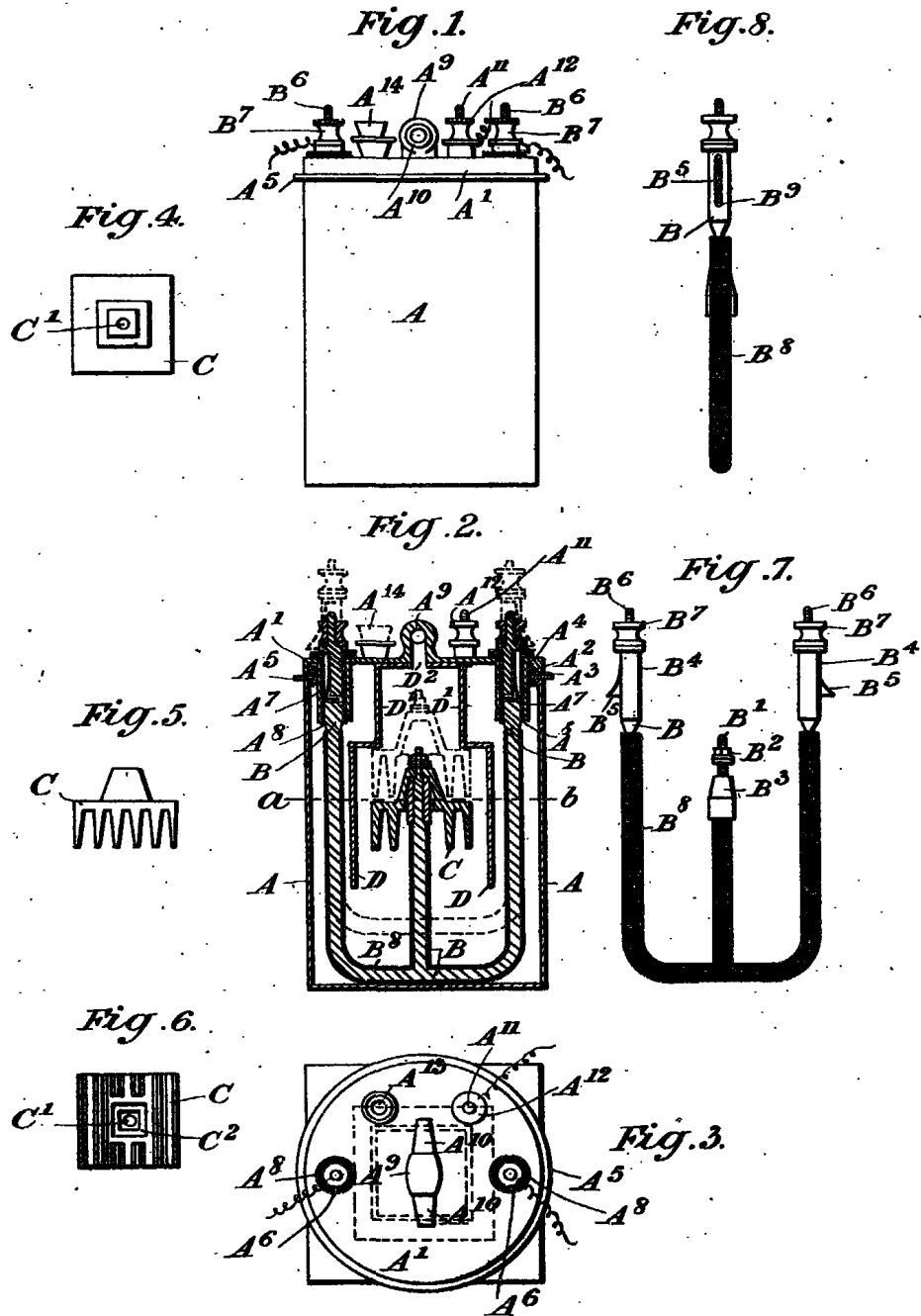
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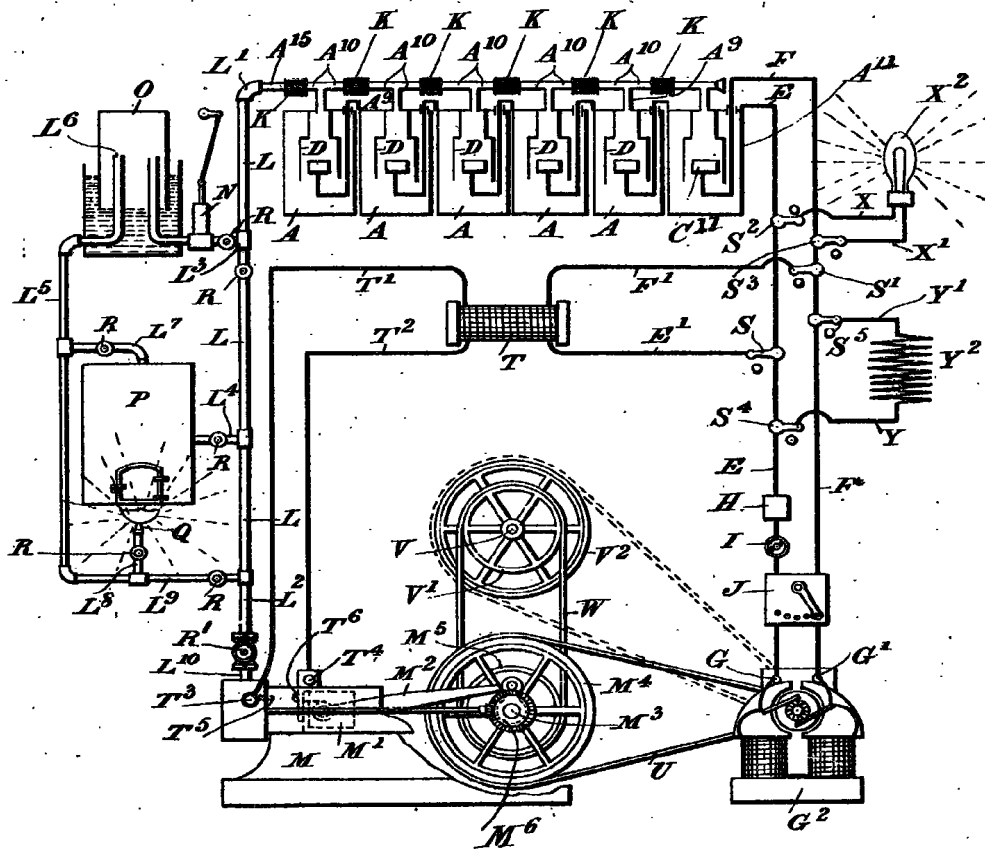
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WATTLES' COMPLETE SPECIFICATION.

SHEET 1.



(2 SHEETS)  
SHEET 2

Fig. 9.



[This Drawing is a reproduction of the Original on a reduced scale.]

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*Date of Application, 29th June, 1897—Accepted, 31st July, 1897*

### COMPLETE SPECIFICATION.

#### **Improvements in and connected with, and Apparatus for, the Manufacture or Production of Hydrogen Gas.**

We, LEOPOLDO VITTORIA PRATIS, and PIETRO MARENGO, both of 33 Via Principe Tommaso, Turin, in the Kingdom of Italy, Manufacturers, do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

5 This Invention relates to the industrial production of hydrogen gas, use for any to which such gas may be applied. We intend to employ it in place of coal gas as an agent for raising refractory bodies or mantles to incandescence, for illumination, and as a heating agent for cooking and similar purposes, and in admixture with air as an explosive agent for generating motive power in suitable engines;  
10 and our invention provides means to enable it to be thus employed, but whilst our said invention is specially intended for such uses of the hydrogen gas produced in accordance with our present invention, we do not restrict ourselves to such uses.

It has long been known that iron is capable of reacting with sulphuric acid, with the formation of sulphate of iron and the elimination of hydrogen gas; and processes have been proposed for utilizing this reaction. Heretofore, however, such  
15 processes have been practically unavailable, and have, so far as we are aware, been employed (when used at all) only occasionally and for limited times, more in the way of experiment than in an industrial manner. Among the objections attending such old processes, or certain of them, may be mentioned the slow generation of the  
20 hydrogen, the obtainment of the sulphate of iron in very dilute solution from which the sulphate of iron cannot economically be separated, and the crystallization of the ferrous sulphate among the particles of iron in the generator, so as thereby to form a hard mass which can with difficulty be removed.

By our present invention the reaction of iron on sulphuric acid is utilized, whilst  
25 at the same time the difficulties above mentioned are avoided. In accordance with our said invention the iron in small particles is placed in a suitable generator and the sulphuric acid admitted upon the iron in such proportion, and in such dilution, as to form (as the result of the reaction) a pasty mass of iron, ferrous sulphate and water, it having been discovered by us that in these proportions there  
30 is a rapid generation of hydrogen with a practically complete saturation of the sulphuric acid and with the formation of a residue which can be emptied by dumping (say by simply dropping the bottom of the generator) and which can be economically utilized in the production of by-products, as for example green vitriol (crystallized ferrous sulphate) and Nordhausen sulphuric acid. Suitable proportions  
35 are about equal weights of subdivided iron, water and sulphuric acid of 50° Baumé, the last being, most advantageously, somewhat in excess, say 5·8 parts by weight sulphuric acid of 50° B. to 5 parts by weight of water and 5 parts by weight of iron.

The full supply of acid may be introduced all at the start; but where the gas is to  
40 be conducted through pipes to the place of utilization, it is advantageous to admit

[Price 8d.]

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the acid gradually to the iron, the water being first mingled with the iron, or with the acid, or being admitted to the iron along with the acid; and it is also advantageous to control the admission of the acid by a cock, or valve, which is automatically controlled by the bell of the gasometer, which receives the gas from the generator.

Where the gas is to be used in places which have no pipe connection with the gas works, as in vehicles for example, or it may be in houses having no pipe connection with the gas-works, it is considered most advantageous to admit the whole proportion of acid at the start, so as to get the compressive effect of the very energetic chemical action which results. The gas may be stored in suitable receptacles (such as for example as bottles composed say of strong metal tubes) under the strong pressure effected by the chemical action. The gas may of course also be obtained under pressure of chemical reaction by a gradual admission of the acid; but by admitting the acid and water to the iron at the start in the predetermined proportions, it is not required to introduce the acid against the high pressure which obtains in the generator during the generation under pressure of the gas.

The invention also comprises such other, or further parts, improvements and combinations, as are hereinafter set forth.

In the accompanying drawings,

Figure 1 is a diagram of apparatus in accordance with the invention.

Figures 2, 3, 4 and 5 are views of the generator, in front elevation, in side elevation partly in section, in bottom view and in plan respectively.

Figures 6, 7, 8 and 9 are views of a gas check and safety device, in end view, in longitudinal section, in cross section and in side elevation respectively, and

Figures 10 and 11 are views in elevation and horizontal section respectively of a tap, or valve, which may, with advantage, be used in some cases for regulating the admission of acid to the generator.

The generator A is a vessel of suitable strength of wrought, or cast, iron, or of copper lined with lead, provided with pipe connections as hereinafter explained and with means for dumping the residue after running off the hydrogen for a charge, the means shewn consisting of a bottom 7 which can be dropped to empty the generator of its contents.

The bottom being in place and the top uncovered, the iron is introduced in a subdivided condition, such as iron filings, or borings, or the like. Any suitable form of iron (wrought iron, cast iron, or other form) which will readily react with sulphuric acid will answer. The vessel should be of such size that the full amounts of iron, water and sulphuric acid, for a run, will about half fill it.

The water (to an amount equal in weight to the iron) may be let into the generator from the elevated vessel B through the pipe 6 by opening a tap or cock at 1; and the acid of 50° B. may be let in from the elevated vessel C through the pipe 5 by opening a tap or cock at 3. The pipes 5 and 6 should be of lead, and (especially if the liquids are to be introduced gradually) should be provided with traps of say one, to two, metres depth, according to the back pressure under which the gas is generated. The vessels B and C are shewn provided with gauges to indicate the litres of liquid therein. For each five kilogrammes of iron in the generator A, five litres of water and three and nine tenths litres of acid of 50° B. (so as to give 5 kilogrammes of water and 5.8 kilogrammes of acid of 50° B. to each 5 kilogrammes of iron) may be let into the said generator either all at the start, or gradually, as may be considered expedient. These proportions will give about a cubic metre of hydrogen, under atmospheric pressure (760 m. of mercury).

Before allowing the hydrogen to pass to the hydrogen receiver, the plug 4 should be opened until the air has escaped. Then the plug being closed, and the tap at 2 being opened, the gas passes through the washing vessels D and E and the gas check and safety device at H to the gasometer G. The vessels D and E may be made of any suitable materials (as iron, or copper, lined with lead), and may contain any suitable purifying agents such as water in the vessel D and a solution of a salt of lead in the vessel E. This latter removes any sulphuretted, arseniuretted, or phosphoretted, hydrogen, which the gas may contain.

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The device H (see Figures 6 to 9) consists of a tubular case with a series of perforated or reticulated diaphragms *a*, therein, which may be made of closely woven wire gauze, placed at short distances apart. These serve to check the flow of the gas, so that if the generation tends to become excessive, the pressure rises in the generator A, and (if the taps of pipes 5 and 6 are open) forces the acid out, so that the generation of hydrogen is temporarily interrupted. The perforated diaphragms also serve to prevent flame (in case of accident) from passing back to the generator.

From the gasometer G the gas passes through an insulating water valve I; then it traverses another device at M similar to the one at H and lastly passes off by the branch pipes N. O. P. to the places of utilization.

The water valve I is provided as additional means of precaution, but it may be dispensed with if preferred.

If the production of hydrogen gas is to take place automatically, there may be substituted for the hand-operated tap or valve 3 in the pipe 5, or be employed in addition to such tap 3, a cock or valve as at R, so connected with the gasometer G as to be operated thereby. When the bell of the gasometer G rises the finger 8 thereon is withdrawn so that the cock R may close and the supply of acid may be temporarily interrupted. When the bell of the gasometer G falls, the finger 8 opens the cock R automatically and a further supply of acid flows into the generator.

Any suitable cock or valve could be used at R and any suitable connection can be employed between it and the gasometer bell; but a special improvement consists in a form which closes when the gasometer bell descends below a predetermined limit. The object of this is that when the supply of acid in the vessel C (which should be in amount proportionate to the charge of iron in the generator) is exhausted, the pipe 5 shall be automatically closed. Referring to Figures 10 and 11 the plug of the cock R (which is preferably made of an alloy of four parts by weight of lead and one part by weight of antimony) is connected with a bent lever S, provided with a weight S<sup>1</sup> which tends to maintain the said cock in its closed position. On the other arm of the lever S is pivoted a finger T which can be lifted independently of the arm of the lever S; but which when depressed carries the lever S with it. This finger T has a depending arm provided with a weight T<sup>1</sup> for returning it after it has been lifted.

At the start the cock R is opened by hand, until sufficient acid has entered the generator A to produce so much gas as to lift the bell of the gasometer G and thereby bring the finger 8 above the finger T. Then, through the consumption, the gasometer bell falls and the finger 8 depresses the finger T, and turns the cock R so as to admit more acid to the generator, whereupon the bell rises again, and the weight S<sup>1</sup> closes the cock R. This automatic opening and closing of the valve R is repeated, so as to supply the acid gradually in proportion to the consumption.

When the supply of acid in the vessel C is exhausted, the bell no longer rises after opening the cock R, but continues to descend. The finger 8, after depressing the lever S to its full extent slips off the finger T and the weight S<sup>1</sup> closes the valve. Should the bell rise in any case after the finger 8 has passed below the finger T this latter is free to be lifted thereby; but as soon as the finger 8 has passed upward, the weight T<sup>1</sup> brings the finger T back into the path of the said finger 8.

When it is desired to obtain hydrogen gas in receivers under strong pressure, say from ten to fifty atmospheres, a suitable receptacle may be connected with the generator by a pipe (provided with a tap) with or without, the interposition of purifying vessels as may be necessary or expedient. When the receptacle is being filled under pressure the tap leading to the gasometer is closed; the requisite amounts of water and acid (as well as of iron) should have been introduced in the generator A, before a high pressure has accumulated therein; although the liquids could be forced in during the generation, against the pressure inside. Knowing the capacity of the receiver and the pressure desired therein, it is easy to calculate the amounts of iron, water and acid to be used from the data hereinbefore given. At the end of the operation, the tap leading to the receptacle is closed and the com-

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pressed gas in the upper part of the generator A is let into the gasometer G, by opening the tap 2.

Whether the hydrogen has been generated under atmospheric or superatmospheric pressure, the elimination of the hydrogen takes place rapidly and with a practically complete saturation of the sulphuric acid; and there remains in the generator a 5  
pasty mass of iron, ferrous sulphate and water, which will fall out of the generator, without leaving incrustation therein, and which is in such condition that it can easily be taken away and utilized for by-products or for revivifications.

With the generator shewn, the bottom 7 is dropped, and the pasty residue deposits itself in the receiver F below. Thereupon the said generator is ready to receive a 10  
new charge of subdivided iron, water and acid of 50° B.

To utilize the residue, green vitriol and Nordhausen acid (either or both) may be made therefrom. To make green vitriol, the residue (or any desired portion thereof) may be mixed with enough water to separate the soluble ferrous sulphate from the 15  
insoluble residue, and the green vitriol may be crystallized out of the solution so obtained. Or, the residue may be treated with a new supply of sulphuric acid to convert the iron into ferrous sulphate, after the manner customary in making green 20  
vitriol from iron and sulphuric acid. To make Nordhausen acid, the residue is dried and roasted. The iron in the roasted residue may be separated from the iron oxide by sifting. This iron, or the iron which may remain after washing off 20  
the ferrous sulphate, may be used again in the generator A as a part of a fresh charge.

While we have specified the use of sulphuric acid of 50° B. we do not restrict ourselves to it, since acid of higher, or lower, specific gravity may be used, (if the 25  
amount of water be increased, or diminished, proportionately) without altering the relative proportions of sulphuric acid ( $H_2SO_4$ ) water ( $H_2O$ ) and iron (Fe) in the generator.

We believe that we are the first to utilize a pasty mass of iron, ferrous sulphate, and water, for the recovery of products formed by the reaction of sulphuric acid 30  
of suitable dilution on iron, and more especially of such products as green vitriol and Nordhausen acid, either or both, for which purpose, or purposes, such paste has advantages; and such utilization we believe to be new, even if the hydrogen gas generated by the reaction should not itself be utilized; but in conjunction with the recovery and utilization of the hydrogen, it constitutes a further new combination 35  
or improvement.

The combination of gasometer and cock controlled thereby is not broadly new; but the further combination of the cock and gasometer with a hydrogen generator 40  
containing an oxidizable metal is believed to be new; and broad novelty is believed to exist (irrespective of the hydrogen generator) when the combination of cock and gasometer bell is such that the cock automatically closes when the bell sinks below a predetermined level, and is opened and closed by the fall and rise of the Bell at 45  
higher levels.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed we declare that what 45  
we claim is:—

1. The process of producing hydrogen gas, by bringing in contact with iron such proportion of sulphuric acid and water as to form in the generator at the end 50  
of the operation a pasty mass of iron, ferrous sulphate and water that is to say the proportion of about equal parts by weight of iron, sulphuric acid of 50° B. and water, substantially as hereinbefore described.

2. In conjunction with the bringing of iron and sulphuric acid together in such relative proportions and with so much water as to form in the generator a pasty 55  
mass of iron, ferrous sulphate and water at the end of the reaction, the treatment of the said mass for the recovery of bye products, more especially green vitriol and Nordhausen acid, either or both, the iron being recovered when thought expedient

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for return to the generator as part of a new charge, substantially as hereinbefore described.

3 In conjunction with the production for use of hydrogen gas by the bringing of iron and sulphuric acid together in such relative proportions and with  
5 so much water as to form in the generator a pasty mass of iron ferrous sulphate and water at the end of the reaction, and collecting the hydrogen gas so generated, the treatment of said mass for the recovery of bye products, more especially green vitriol and Nordhausen acid, either or both, the iron being recovered when thought expedient for return to the generator as part of a new charge substantially as  
10 hereinbefore described.

4. The process of producing hydrogen gas, by bringing in contact with iron in a generator such proportions of sulphuric acid and water as to form in the generator at the end of the operation a pasty mass of iron, ferrous sulphate and water and discharging such paste by gravitation so as to leave the generator empty for a new  
15 charge substantially as hereinbefore described.

5. The improvement in obtaining hydrogen gas under a pressure of several atmospheres, by adding sulphuric acid to iron, and conducting the gas as generated into receptacles or bottles of small capacity as compared with the volume of gas generated, and the hydrogen gas, as generated being confined so as to be compressed  
20 into bottles or the like by the reaction of the sulphuric acid on the iron, substantially as hereinbefore described.

6. In combination with a hydrogen generator supplied with an oxidizable metal, an acid holding vessel, a supply pipe connecting the said vessel with the said generator, a cock in the said supply pipe, a gasometer having its bell communicating  
25 with the said generator and having a valve controlling-connection with the said cock substantially as hereinbefore described.

7. The combination with a cock of a gasometer having its bell connected with the said cock by means whereby on the bell sinking below a predetermined level the cock automatically closes, and whereby also the rise and fall of the bell at higher  
30 levels closes and opens the said cock substantially as hereinbefore described.

8. The combination with a hydrogen generator supplied with oxidizable metal, and an acid supply pipe connected with the said generator and provided with a cock, of a gasometer having its bell connected with the said Cock by means whereby on the bell sinking below a predetermined level the cock automatically closes, and  
35 whereby also the rise and fall of the Bell at higher levels closes and opens the said cock substantially as hereinbefore described.

9. The cock having a weighted operating lever provided with a hinged finger which carries the cock-operating lever with it in one direction, but is moveable independently in the opposite direction substantially as hereinbefore described.

40 10. A hydrogen-producing apparatus, composed of a dumping generator, that is to say a generator arranged to discharge its solid contents by gravitation, together with means for supplying the same with metal and acid, and for collecting the hydrogen generated therein, substantially as hereinbefore described.

11. A hydrogen producing apparatus, composed, in combination with the  
45 generator, of a gasometer and connecting pipes, together with means whereby a receiver or bottle for collecting the gas under the pressure of the chemical reaction may be put in communication with said generator, and means for closing the communication with the gasometer during the filling of said receiver or bottle substantially as hereinbefore described.

50 Dated this 28th day of June 1897.

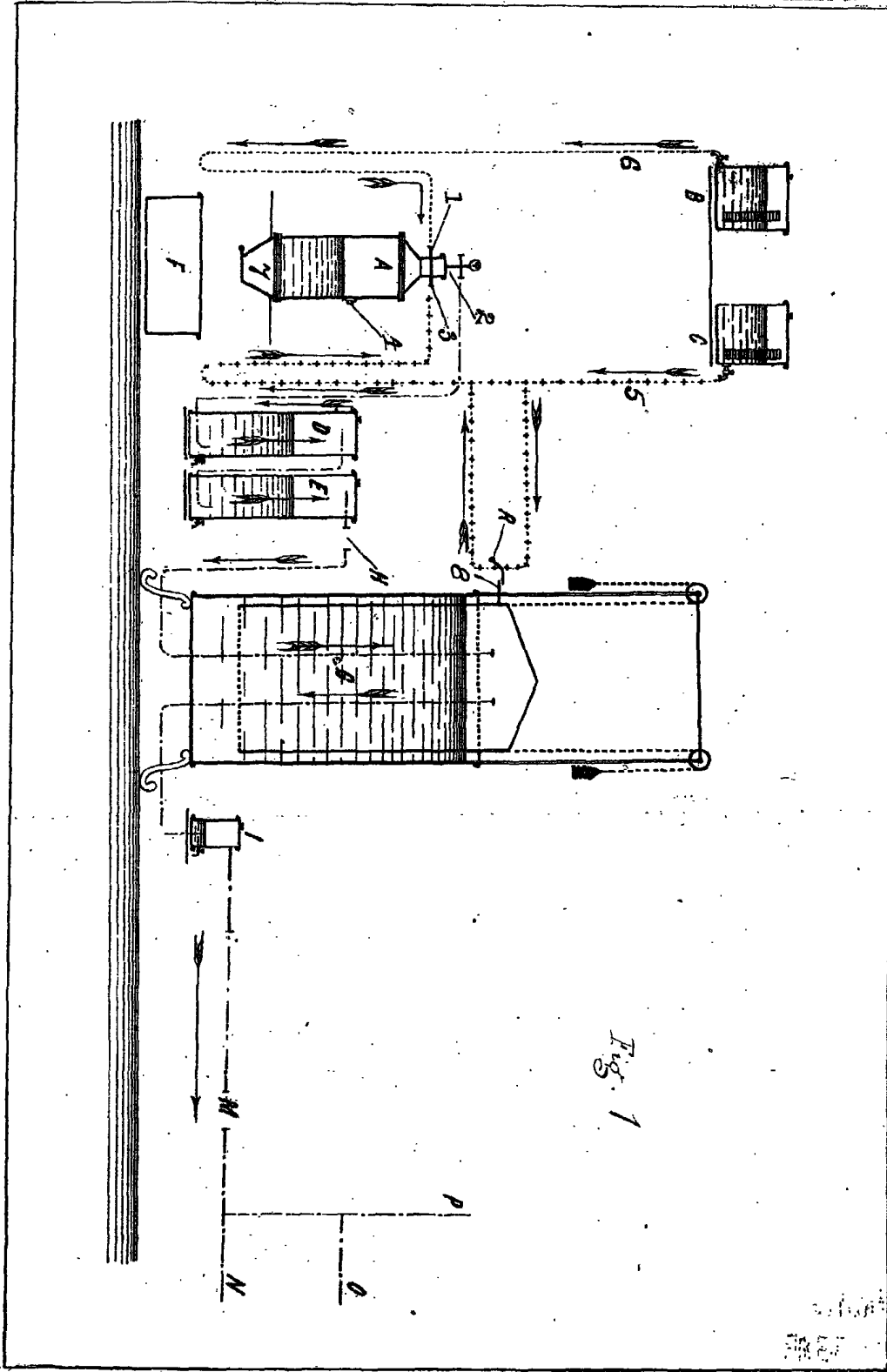
JOHNSONS & WILLCOX,  
47 Lincoln's Inn Fields, London, W.C., Agents.

Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1897.



A.D. 1897. JUNE 29. N<sup>o</sup> 15,509.  
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SHEET 1.

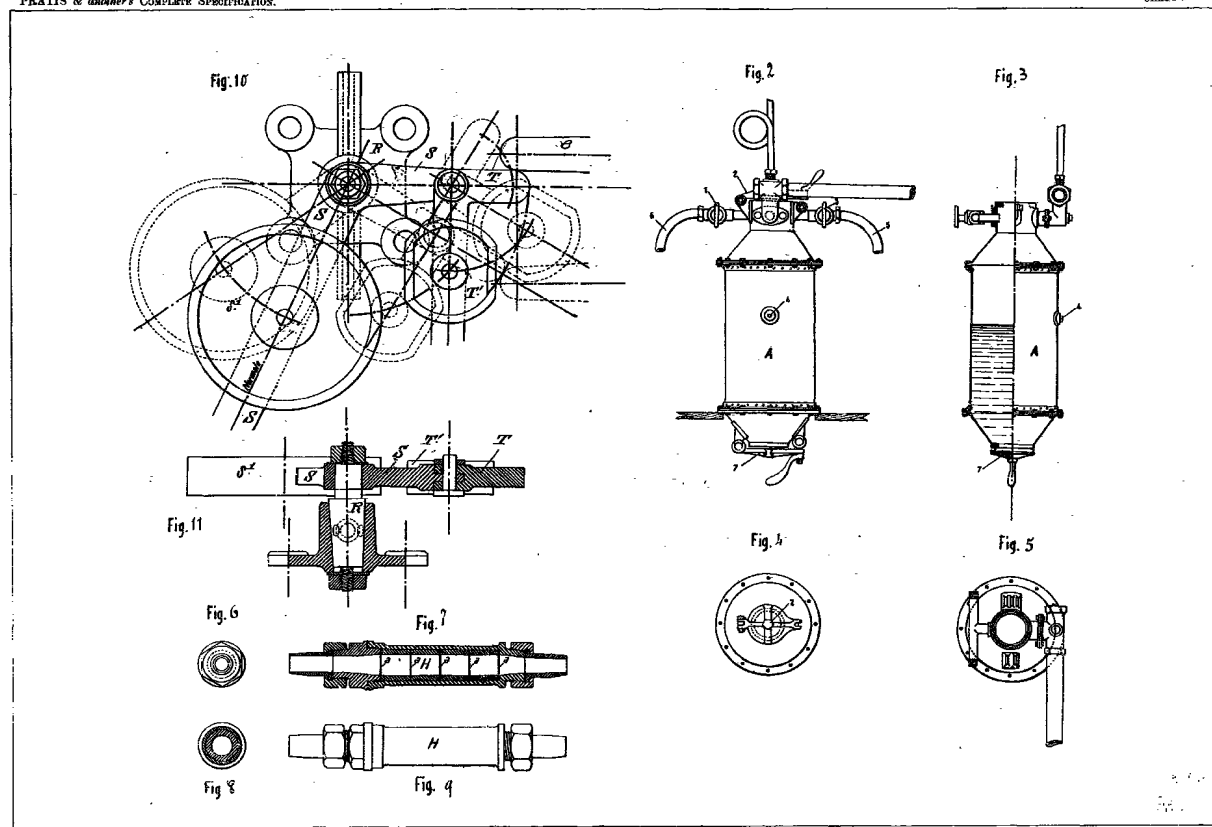


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A.D. 1897, JUNE 29, N° 15,509.  
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SHEET 2



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**PRATIS & another's COMPLETE SPECIFICATION.**

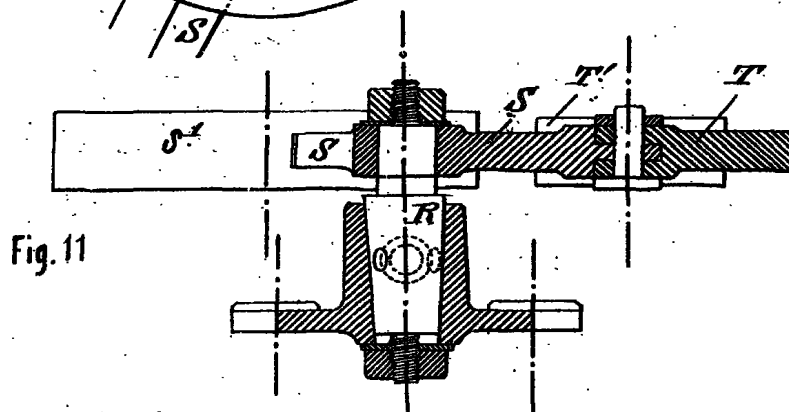
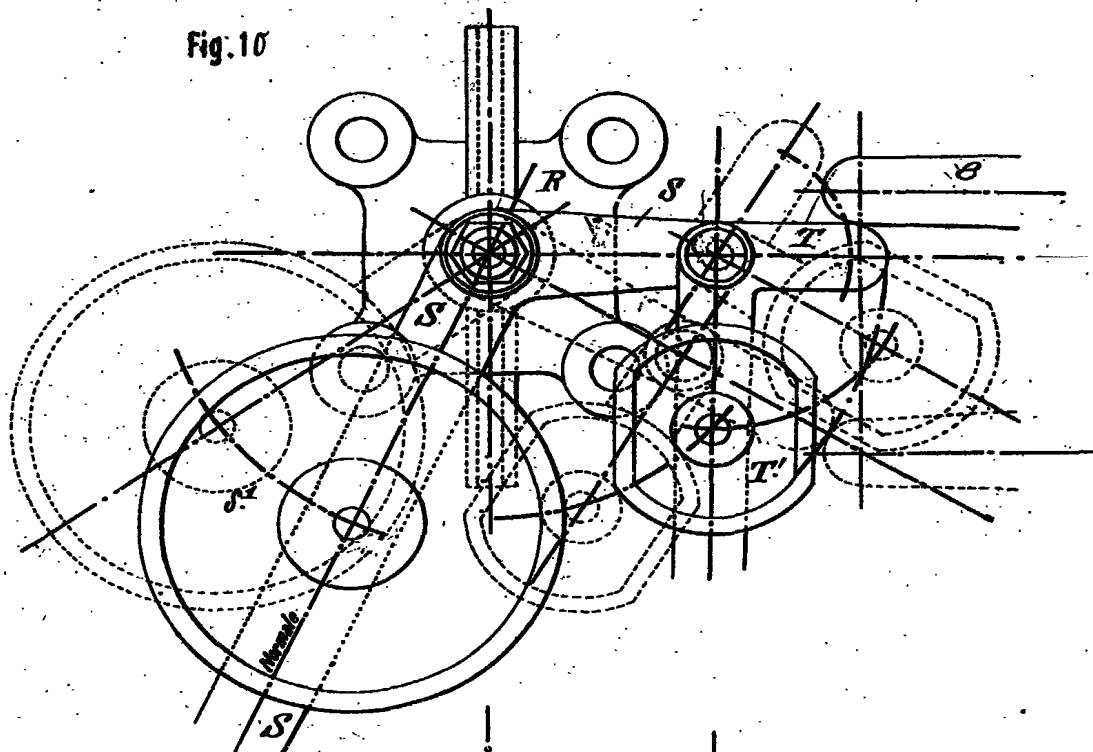


Fig. 6



Fig. 8

Fig. 7

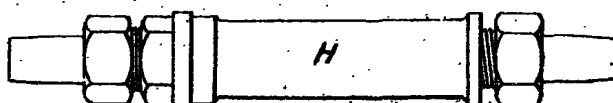
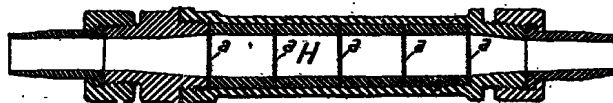


Fig. 9

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SHEET 2.

Fig. 2

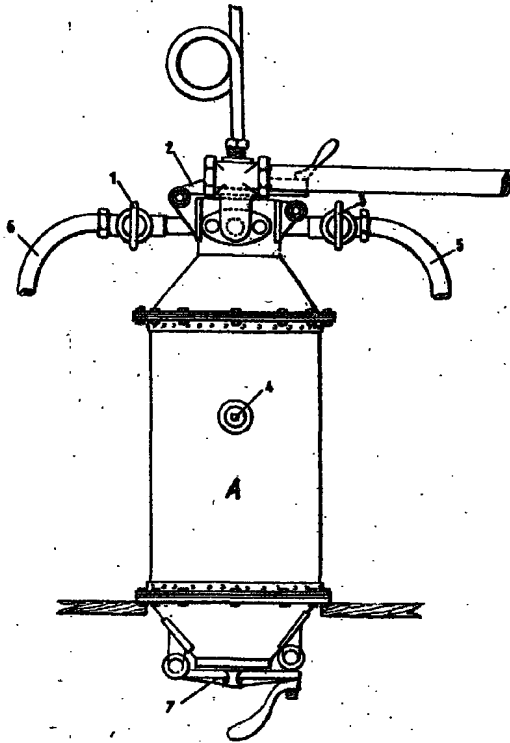


Fig. 3

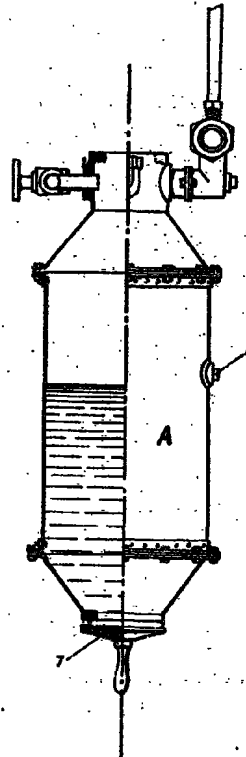


Fig. 4

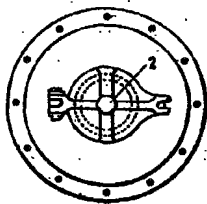
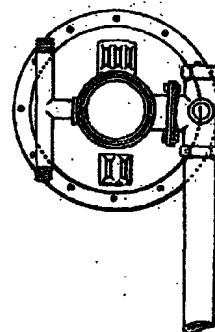


Fig. 5



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N<sup>o</sup> 25,084

A.D. 1897

*Date of Application, 29th Oct., 1897**Complete Specification Left, 29th Aug., 1898—Accepted, 8th Oct., 1898*

## PROVISIONAL SPECIFICATION.

**A New or Improved Hydrogen Gas Generator.**

We, GEORGE HAWKINS, HENRY HAWKINS, and SAMUEL HENRY HAWKINS, all of 250, Green Street, Upton Park, Essex, Gentlemen, do hereby declare the nature of this invention to be as follows;—

Our invention relates to a new or improved hydrogen gas generator, the object  
5 being to facilitate the generation of hydrogen gas by providing an apparatus arranged or constructed in such a manner as to allow of the generation of the gas being continually effected as it is not necessary for the working of the apparatus to be stopped for re-charging *etc.* Our improved apparatus is further of few and simple parts, while ready access may be had to same for cleaning purposes or  
10 repairs.

In carrying our invention into practical effect, our improved generator comprises three superposed chambers each arranged in such a manner as to form a gas tight connection, the upper chamber being designed to contain a supply acidulated water, while the two lower chambers serve as generators.

15 Near the bottom of each of the lower chambers we arrange a suitable grid and upon this is placed the necessary material or materials for the generation of the gas.

We further arrange in connection with these chambers a suitable series of pipes connecting the upper or acid chamber with the lower and upper generators and  
20 also connecting the two generators together, while further balance pipes, vent pipes, and pipes for drawing off the gas are suitably arranged. The necessary gauges, vent taps, waste taps and the like are arranged in any convenient manner and may be of any required form or construction as required.

Each generator is furnished with a manhole, while the cover or lid of the acid  
25 tank or chamber is preferably formed with a flange designed to enter a suitable U-shaped channel or recess formed around the edge of the tank or chamber and containing water, thus forming a gas tight connection between same.

With our improved apparatus one or both generators may be used at a time by opening the taps or cocks of the supply pipes, so as to allow of the acid gaining  
30 access to the generating chamber or chambers, while when it is necessary to re-charge one of them the working of that chamber can be stopped, while the second chamber continues the generation of gas, so that no stop in the working is necessary.

Our improved gas generator is automatic in its working, in so far that in the  
35 event of the gas being generated in larger quantities than is required for immediate use it fills the generators, forces back the liquid through the supply pipes until it is below the grid, thus placing the material or materials necessary for the generation of the gas above the acid mixture.

As our improvements are capable of modifications, without departing from the

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N<sup>o</sup> 25,084.—A.D. 1897.*G., H., and S. H. Hawkins's New or Improved Hydrogen Gas Generator.*

principle thereof, we do not restrict ourselves to dimensions, materials, or to the precise form or placement of the several parts thereof.

Dated this 28th day of October 1897.

F. G. CASSELL,  
(Of Cassell & Co.),  
22, Glasshouse Street, Regent Street, London, W.,  
Agent for the Applicants.

5

## COMPLETE SPECIFICATION.

**A New or Improved Hydrogen Gas Generator.**

We, GEORGE HAWKINS, HENRY HAWKINS, and SAMUEL HENRY HAWKINS, all of 10  
250, Green Street, Upton Park, in the County of Essex, Gentlemen, do hereby  
declare the nature of this invention and in what manner the same is to be per-  
formed to be particularly described and ascertained in and by the following state-  
ment:—

Our invention relates to the novel construction of an apparatus in which hydrogen 15  
gas is produced by the action of diluted sulphuric acid upon iron or zinc.

In order that our invention may be clearly understood reference is made to the  
accompanying drawings, in which,—

Figure 1, represents a front elevation of the generator, shewing the arrange-  
ment of the chambers and pipes connected therewith, and

20

Figure 2, is a section through the chambers.

In carrying out our invention we form three separate vessels or chambers (A),  
(B) and (C) of copper or other suitable material capable of resisting the action of  
the acid we employ. These are arranged in the manner illustrated; the upper  
one being designed to contain sulphuric acid and water in suitable proportions, 25  
while the two lower ones hold iron or zinc shavings, borings or turnings. The  
said metal is supported on a grid or perforated plate (D) arranged in the lower  
portion of each of the chambers (B) and (C). It is fed into the said chambers  
through the hand holes (E) and (E<sup>1</sup>).

The aperture in the upper chamber through which the acidulated water is 30  
poured is furnished with a cap or cover (F) which rests in a channel or recess (F<sup>1</sup>)  
around the said aperture containing water so as to seal the connection between  
the same.

A pipe (G) furnished with a cock (G<sup>1</sup>) is led from the lower portion of the acid  
chamber (A) to beneath the grid (D) in the lower chamber (C) to convey the 35  
acidulated water to the metal. A similar pipe (H) is led to the middle chamber (B)  
so that either one of these chambers can be worked independently of the other.  
Another pipe (I) fitted with a cock (I<sup>1</sup>) connects with the lower portions of the  
middle and bottom chambers (B) and (C) so that the liquid from one chamber can  
be forced by the pressure of gas into the other when necessary. Suitable gauge 40  
glasses (J), (J<sup>1</sup>) and (J<sup>2</sup>) are secured to the chambers to shew the height of liquid  
therein.

The pipes (K) and (K<sup>1</sup>) communicating with the upper portions of the  
chambers (B) and (C) preferably connect with the pipe (K<sup>2</sup>) leading to the top  
chamber and serve to convey the air in the lower chambers to the upper one when 45  
first starting the apparatus. (L) is a vent pipe to enable the air or gas that finds  
its way to the top chamber to escape. (M) and (M<sup>1</sup>) are pipes which extend to  
the central portions of the chambers (B) and (C) to convey the gas from the same  
to the outlet pipe (M<sup>2</sup>). (N) is the balance pipe for the middle chamber and (N<sup>1</sup>)

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is the balance pipe for the lower chamber. These pipes may be termed the safety valve arrangements of the apparatus.

A cock such as (O) is fitted in the lower portion of each chamber for drawing off the acidulated water and spent liquid when necessary, or if desired the spent liquid may be blown through pipes secured to the branches (P) and (P<sup>1</sup>) on the balance pipes. The latter arrangement is more especially for use when the apparatus is employed for supplying gas to engines for driving boats.

The lower chambers (B) and (C) may each be fitted with a plug (Q) which can be removed when it is desired to clean the interior of the same, instead of having to remove the hand hole cover, for this purpose.

All pipes are furnished with cocks where required for the proper working of the apparatus also plugs for clearing the pipes when necessary.

In the drawings it is assumed that the bottom chamber is working, the cocks in the pipes connected therewith are consequently shewn turned on.

The generator is automatic in its working in so far, that in the event of the gas being generated in larger quantities than is required for immediate use, it fills the generator and forces back the liquid through the supply pipes until it is below the grids, thus placing the metal necessary for the generation of the gas above the acid mixture.

As our invention is capable of modification without departing from the principle thereof, we do not restrict ourselves to size, materials, or to the precise form or placement of the several parts thereof.

By the use of this invention gas can be continuously generated, as when one generating chamber becomes practically exhausted the other is in readiness to be worked; moreover the spent solution can be used until it is completely worked out.

The construction of our generator is such that the chambers and fittings thereof can be taken apart so as to facilitate its removal and repairs when necessary.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

Firstly. A hydrogen gas generator constructed and operated substantially in the manner as herein set forth.

Secondly. In hydrogen gas generators the combination of the chambers (A), (B) and (C), the liquid supply pipes, the pipe (I), the vent pipes, balance pipes, gas outlet pipes, gauge glasses, drain cocks and other fittings, the whole being constructed and arranged substantially as and for the purposes herein set forth.

Thirdly. In hydrogen gas generators the chambers (A), (B) and (C) and fittings thereof made detachable so that they can be taken apart substantially as and for the purposes herein set forth.

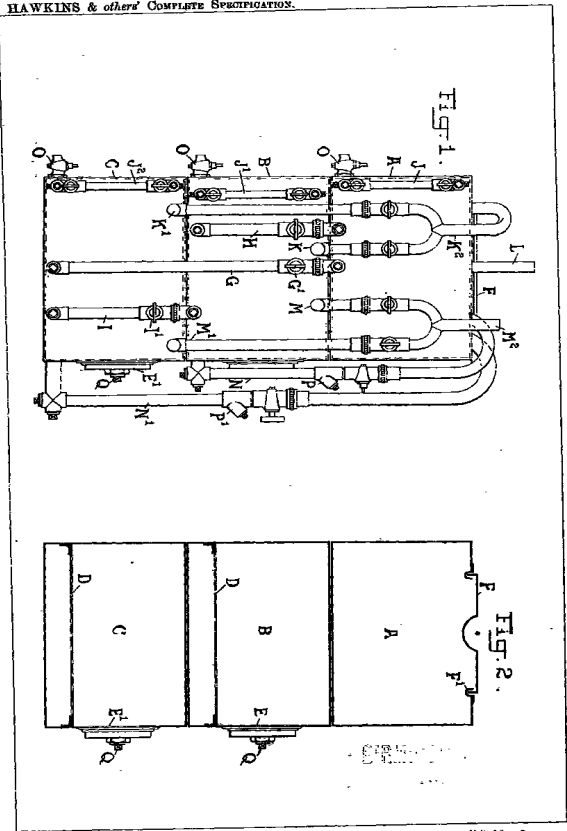
Dated the 29th day of August 1898.

W. D. ROWLINGSON,  
7, Quality Court, Chancery Lane, London, W.C.,  
Agent for the Applicants.

Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd—1898

A.D. 1897. Oct. 29. N° 25,084.  
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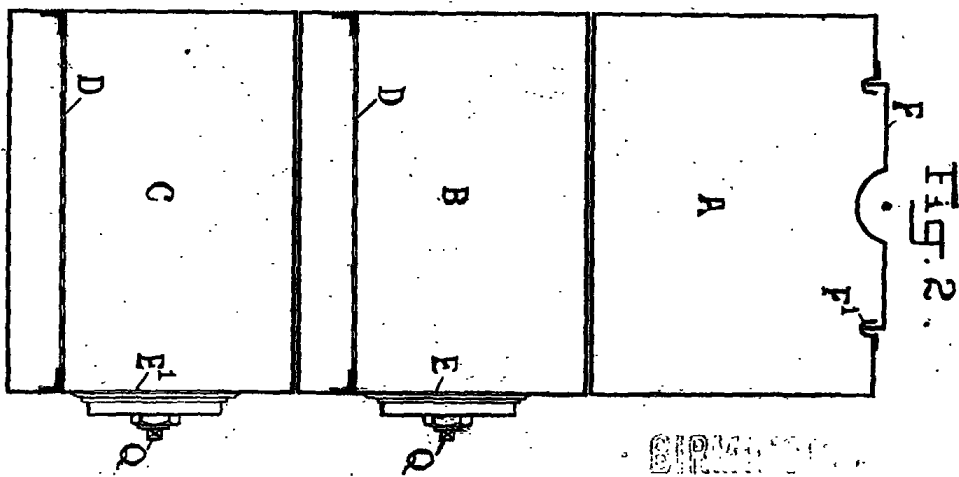
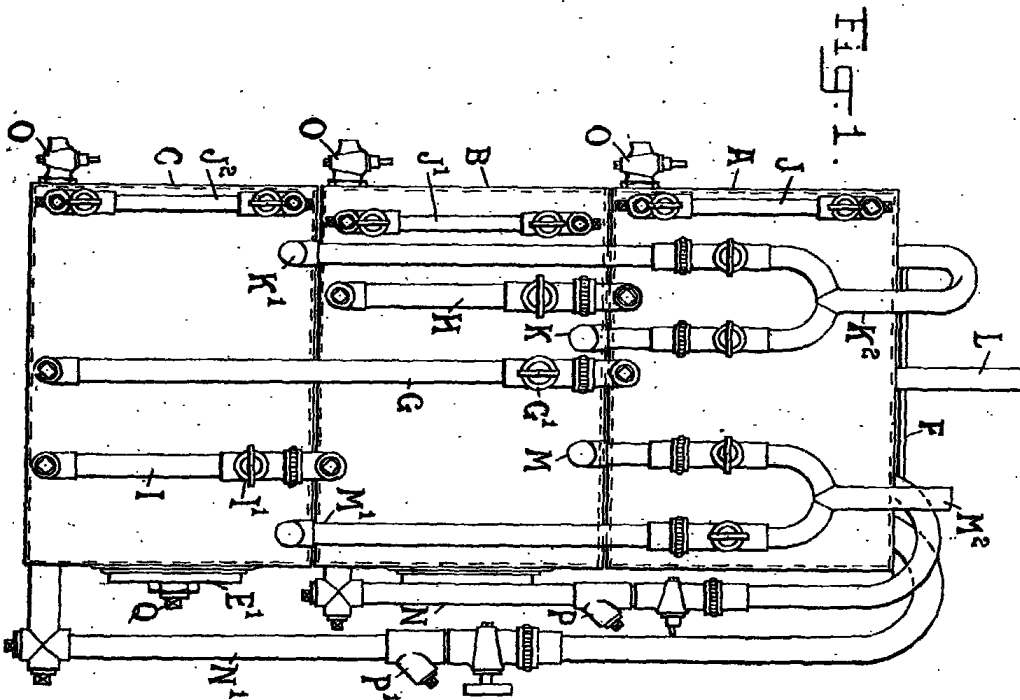
Maly & Son's Press Ltd



A.D. 1897. Oct. 29. N<sup>o</sup> 25,084.

HAWKINS & others' COMPLETE SPECIFICATION.

(1 SHEET)



[This Drawing is a reproduction of the Original on a reduced scale.]

Malby & Sons, Photo-Litho.

N<sup>o</sup> 6006

A.D. 1898

*Date of Application, 11th Mar., 1898**Complete Specification Left, 12th Dec., 1898—Accepted, 28th Jan., 1899***PROVISIONAL SPECIFICATION.****Improvements in Gas Generators for Acetylene, Hydrogen, and such like Gases.**

I, JOHN PERCIVAL, of 103, Miles Buildings, Edgware Road, London, Iron and Tinsplate Worker, do hereby declare the nature of this invention to be as follows:—

I first provide a gasometer tank dipping into same is the usual bell part, round  
 5 the inside of which is a projecting or thick portion to displace water, within the tank outside the bell is a coil of pipes for the gas when generated to pass through to be cooled before consumption. On the outside of the tank is arranged the gas generator. This is preferably formed as a cylinder in communication by side passage with the tank so that the water in cylinder and tank will be at the same  
 10 level. The top of cylinder is arranged to be removed at will and secured gas tight by suitable means such as packing and thumb screws, within the cylinder is provided a suspended perforated cage to hold the calcium carbide. The rod by which the cage is suspended projects outside the cover and is fitted with a handle or knob to enable the cage to be lifted out of the water to stop the generation of  
 15 gas. A pipe fitted with tap conducts the gas from upper part of cylinder into the gasometer, when the pressure of gas lifts the bell and so withdraws the thick portion from the water which consequently goes to a lower level, thereby withdrawing the water from the cage, and automatically stopping the generation of gas. On the pressure of gas being reduced by the gas being drawn off, the lower-  
 20 ing of the bell causes the water to rise to reach the calcium carbide when the generation again takes place. A safety valve arrangement is provided which acts automatically when the bell rises to a certain height, to cause the level of the water to fall. This safety arrangement consists of a bent pipe, the bent portion extending down to a distance so that when the water is at its lowest level  
 25 the end of the pipe will be out of the water, and thus allow the gas to escape into the pipe, the pipe being carried outside the gasometer, and thus the gas will escape into the air, but this escape will be at once stopped by the falling of bell which will cause the water in tank to rise and seal mouth of pipe. The bottom of generating cylinder is fitted with means to enable the bye products of the  
 30 carbide to be withdrawn. The above apparatus can be used for generating hydrogen gas by adding acid to the water and substituting metal for carbide.

Dated this 11th day of March 1898.

FREDERIC PRINCE,  
Agent for Applicant.

[Price 8d.]

2

N° 6006.—A.D. 1898.

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*Improvements in Gas Generators for Acetylene, Hydrogen, and such like Gases.*

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## COMPLETE SPECIFICATION.

**Improvements in Gas Generators for Acetylene, Hydrogen, and such like Gases.**

I, JOHN PERCIVAL, of 103, Miles Buildings, Edgware Road, London, Iron and Tinplate Worker, do hereby declare the nature of this invention, and in what manner the same is to be performed to be particularly described and ascertained, in and by the following statement:—

This invention refers to improvements in apparatus for the production of acetylene, hydrogen and such like gases, the improved apparatus comprising a gasometer, the inverted bell of which serves not only for the storage of the produced gas, but is so arranged and constructed that its rise and fall in the tank, regulates and governs the rate of production of the gas, or causes the production to cease, this action is effected by permitting the rise and fall of the bell to produce a variation of the level of the water or other liquid, in a gas generating cylinder or cylinders, and thereby allowing the water when its level is relatively raised in the generating cylinder, to act upon calcium carbide (if acetylene gas is to be produced) or other material, the production of gas being discontinued by the rise of the bell withdrawing the gas generator cylinder or cylinders, and thereby causing the water level to be lowered within same. 15

A safety valve is also provided which acts automatically, when the inverted bell has risen to a predetermined height.

Convenient means are provided for the insertion and removal of the calcium carbide containers to and from the generator cylinders and the produced gas is delivered in a cooled state by its passage through a coiled pipe immersed in the gasometer tank. 20

My invention will be readily understood by describing the same with reference to the accompanying drawings, whereon Figure 1, is a vertical longitudinal section of my improved gas generator, Figure 2 is a horizontal section of same on the line X-Y of Figure 1; Figure 3 is an end sectional elevation of the lower part of the apparatus, and Figure 4 is a detail view in plan hereafter referred to. Similar letters of reference refer to like parts in the several figures of the drawings. 25

According to my invention, I provide a gasometer tank A, to receive the inverted bell B, and upon either side of the bell I form extensions A<sup>1</sup>, of the tank, (see Figure 2,) within which latter extensions, outside the tank proper A, there are located my gas generator cylinders C. Each of these cylinders C, is open at its lower end C<sup>1</sup>, Figure 1, being fixed to and carried by the bell, the said lower ends of the cylinders being in communication with the tank, so that the water in the cylinders C, C, and the tank A, will be at the same level. 35

The tops C<sup>2</sup>, of the cylinders are arranged to be removed at will, and suitable means are provided by which the said covers can be secured gas tight, such for example as the packing rings C<sup>3</sup>, located between the covers C<sup>2</sup>, and the flanged tops of the cylinders C. The covers C<sup>2</sup>, may be secured by thumb screws, or the like, but I prefer the angular section half rings such as D, (see Figs. 1 and 4), drawn together by bolts and nuts, by which action the covers C<sup>2</sup>, are tightly held to the packing rings. 40

Within each of the cylinders I provide a perforated cage E, to hold the calcium carbide, the rod E<sup>1</sup>, by which the cage E, is suspended, passing through a stuffing box in the cover C<sup>2</sup>, and being fitted outside the cover with a handle or knob to enable the cage E, to be raised completely out of reach of the water when it is desirable to stop the generation of the gas. 45

Pipes F, each fitted with stop cocks, extend between the upper parts of the

N<sup>o</sup> 6006.—A.D. 1898.

3

*Improvements in Gas Generators for Acetylene, Hydrogen, and such like Gases.*

generator cylinders C, C, to the interior of the upper part of the bell B, where the open ends of the pipes enter a water filled trough B<sup>1</sup>, and the produced gas passes through the water therein contained into the bell, being thereby filtered.

5 Within the tank I provide a coiled pipe G, the upper open end being within the bell B, above the highest water level, while the lower end passes through the bottom of the tank and communicates with a condensing box G<sup>1</sup>, from whence a pipe G<sup>2</sup>, extends controlled by a cock G<sup>3</sup>. The produced gas is conducted through this coil G, box G<sup>1</sup>, and pipe G<sup>2</sup>, becomes thoroughly cooled, and is delivered for use by the pipe G<sup>2</sup>.

10 At the base of the tank A, Figs. 1 and 2, is a passage H, controlled by a cock H<sup>1</sup>, by which the bye products of the calcium carbide may be removed.

The weight of the bell B, and its attached parts may be counterbalanced by weights J, in the usual manner and it will be readily understood that as the gas is produced the bell will rise, taking with it the generator cylinders C, and thereby  
15 the level of the water in the latter will become altered, that is as the bell B, and the cylinders C, rise the level of the water will be lowered in the cylinders C, and the production of the gas will be lowered or cease altogether. I may provide around the inside of the bell B, a projecting or thickened portion, composed say of an annular air tight chamber K, in order to cause a more rapid displacement  
20 of the water and partial flotation of the bell, and thereby increase the difference of the level of the water quicker than by the rise and fall of the bell only, but in many cases I have found that this is not necessary, and therefore, in such cases, the thickening of the walls of the bell, in order to produce such rapid displacement may be dispensed with.

25 On the pressure of the gas being reduced by the said gas being drawn off the consequent lowering of the bell B, causes the water to rise and reach the calcium carbide when the generation of the gas is again automatically re-commenced.

The safety valve arrangement I provide is constructed to act automatically, when the bell B, rises to a certain height, and to this end, the device consists of  
30 a pipe L, carried by the bell B, and having its upper end closed, while its lower end is open, and apertures are formed in the wall of the pipe L, at L<sup>1</sup>, Figure 1. The gas escape pipe M, extends from outside the tank, passes through the base of same, and up the inside of the tube L, being open at the top. By this arrangement when the bell rises to a certain height, the apertures of the otherwise water  
35 sealed tube L will be brought above the water level, and the gas will escape into the air by the pipe M, the escape being at once stopped by the falling of the bell.

Such apparatus can be employed for generating hydrogen gas by adding acid and water and substituting metal for the calcium carbide.

40 Having now particularly described and ascertained the nature of this invention and in what manner the same is to be performed, I declare that what I claim is:—

1. In gas generators for acetylene, hydrogen and such like gases, the combination with gasometer, of generating cylinders carried by the inverted bell, each cylinder at its lowest end being open to admit the water from the tank, a cage to contain the calcium carbide or equivalent suspended within the hermetically sealed top of each cylinder, pipes extending between the upper parts of each  
45 cylinder to the upper part of the interior of the bell and a stationary coiled pipe located within the bell, fixed in the tank and extending from above the water level, through the water to conduct the produced gases from the bell in a cooled state for use where required, the bell serving not only for the storage of the produced gas but to regulate the rate of production, by its rise and fall producing  
50 relative differences in the level of the water, all arranged and acting substantially as described.

2. The combination with apparatus for the production and storage of acetylene and like gas as claimed by Claim 1, of the arrangement of automatically acting  
55 safety valve adapted to permit the escape of gas when the bell has reached a predetermined height substantially as set forth.

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N<sup>o</sup> 6006.—A.D. 1898.

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*Improvements in Gas Generators for Acetylene, Hydrogen, and such like Gases.*

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3. The particular arrangement and combination of parts composing my improved gas generator for acetylene, hydrogen and like gases, all constructed and acting as and for the purposes described and illustrated with reference to the Figures 1, 2, 3, and 4, of the accompanying drawings.

Dated this day 10th of December 1898.

5

FREDERIC PRINCE,  
37, Cursitor Street, Chancery Lane, E.C., Agent for Applicant.

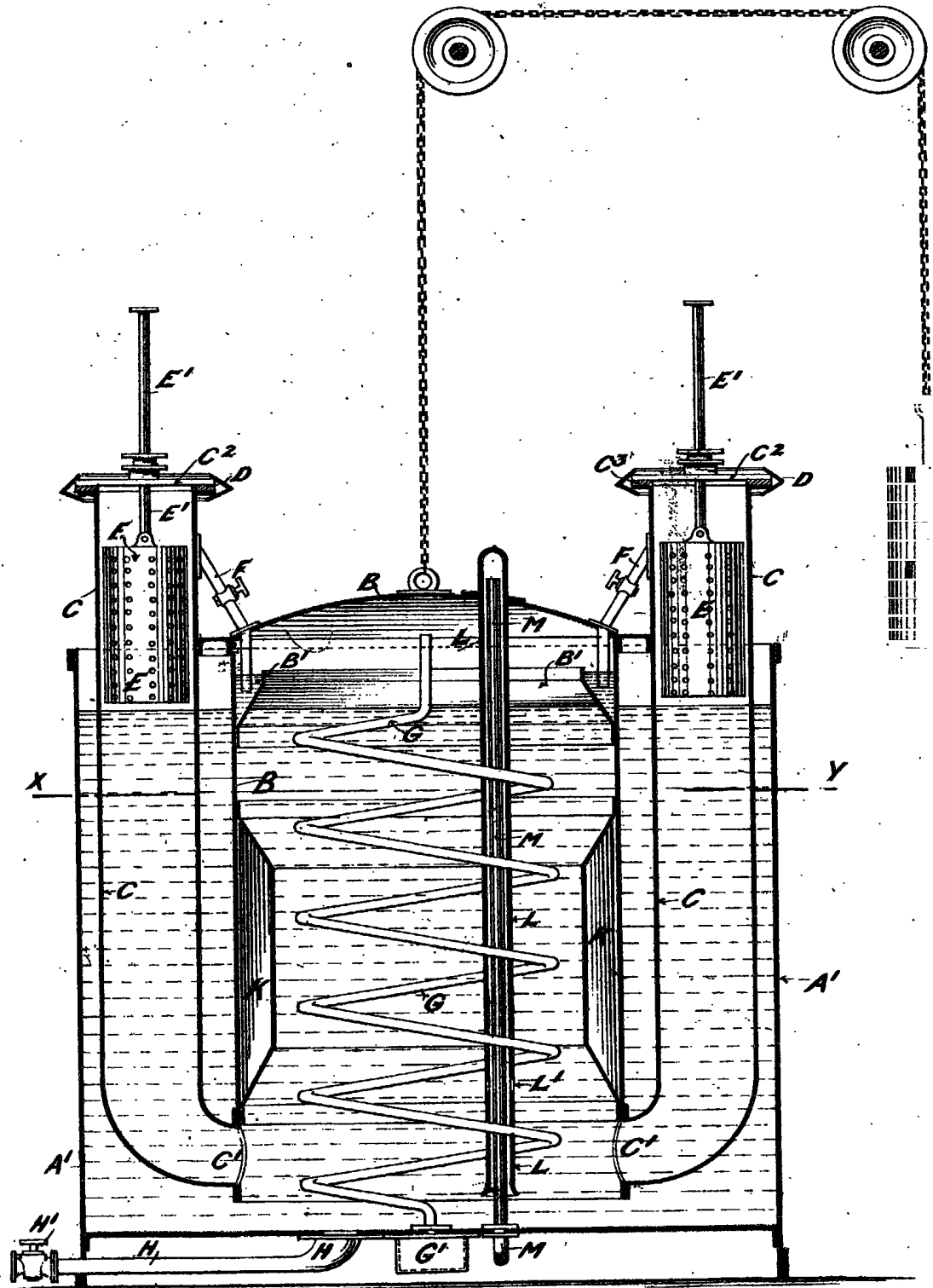
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Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1899.



A.D. 1898. MARCH 11. N<sup>o</sup> 6006.  
PERCIVAL'S COMPLETE SPECIFICATION.

FIG: 1.



(1 SHEET)

FIG: 2.

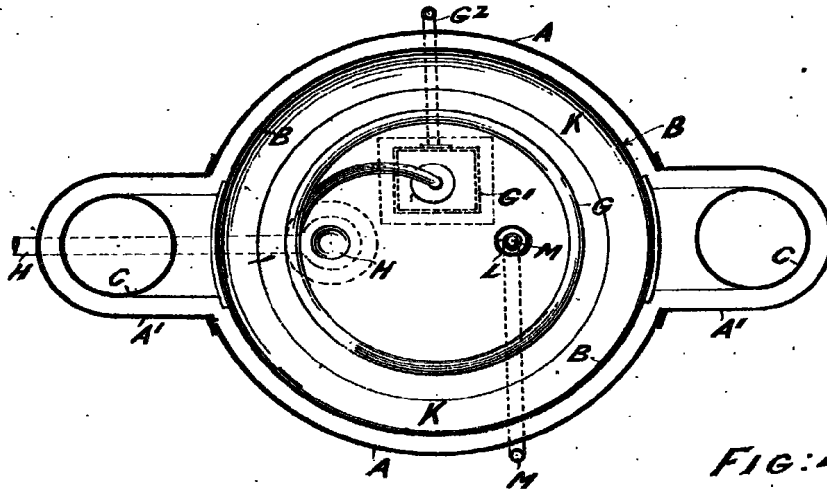


FIG: 4.

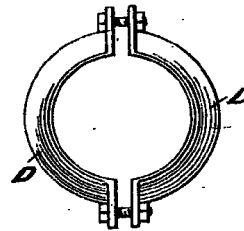
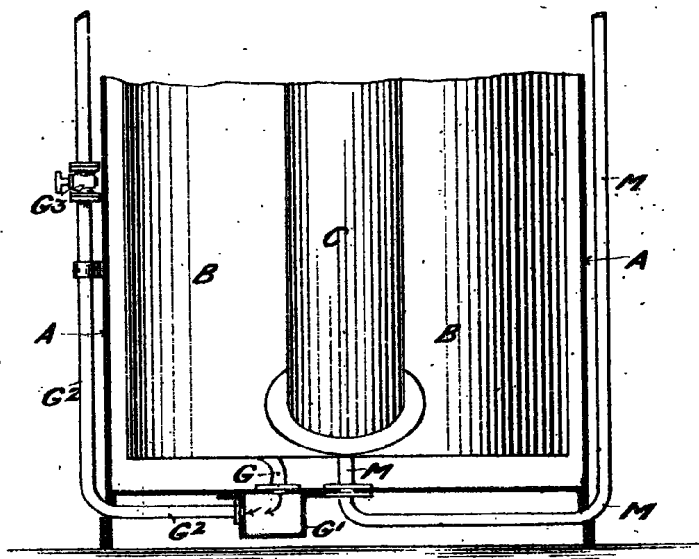


FIG: 3.



[This Drawing is a reproduction of the Original on a reduced scale]

Malby & Sons, Photo-Litho.



N<sup>o</sup> 17,516

A.D. 1898

*Date of Application, 13th Aug., 1898—Accepted, 22nd Oct., 1898*

### COMPLETE SPECIFICATION.

#### Improvements in Apparatus for Producing and Carburetting Hydrogen.

I, JOHN FIELDING, of Belmont, Upton St. Leonards, in the County of Gloucester, Engineer, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in, and by the following statement:—

5 My invention relates to a simple and convenient apparatus for producing and carburetting hydrogen, which is preferably so arranged that the production can be continuously maintained as I shall describe referring to the accompanying drawings.

Figure 1 is a side elevation, Figure 2 is an end elevation and Figure 3 is a  
10 plan of apparatus according to my invention. Figure 4 is a modification.

A A are two cylindrical producer vessels placed side by side at a little distance apart, and B is a carburetting vessel shaped to fit closely between the lower parts of the vessels A A. Within each of the vessels A there is a partition consisting of a part C nearly horizontal, and a tapering tubular part D extending up to  
15 and above the top of the vessel A. In the lower compartment of each vessel A is a perforated plate E of material which is not affected by the acid employed; on this perforated plate are laid fragments of zinc or of iron or steel, these being introduced through a manhole F at the top of tube D which can be tightly closed. Each of the vessels A has at the top a funnel G by which dilute acid,  
20 preferably sulphuric acid, can be introduced, and the carburetting vessel B has a hole with a screw plug or cover H for introducing benzoline or such like somewhat volatile oil.

From the top of each vessel A branch pipes provided with cocks I lead to a pipe J which extends down into the carburetting vessel B, while a pipe K ascends  
25 from that vessel to the service pipe L by which the carburetted gas is led away for use.

A pipe M, provided with cock, leads from the upper compartment of each vessel A to the lower.

Another pipe P leads from the bottom of the lower compartment to the top  
30 of the upper compartment of each vessel A. Manholes R are provided for removing the residue of metal and cocks S are provided for drawing off liquid.

The apparatus operates as follows:—

Either vessel A has its upper compartment charged with dilute acid and its lower compartment with the fragments of metal laid on the perforated plate.  
35 Also the carburetting vessel B is charged with the volatile oil.

The dilute acid flowing in regulated quantity from the upper into the lower compartment through the pipe M, and acting on the metal therein, causes decomposition of the water, generating hydrogen which ascends through D to the top of the vessel and passes down to the carburetting vessel taking up vapour  
40 and passing thence to the service pipe L. By more or less opening a cock Q, more or less of the gas may be allowed to pass direct to the service pipe without

[Price 8d.]

ORIGINAL  
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*Fielding's Improvements in Apparatus for Producing and Carburetting Hydrogen.*

passing through the carburetting vessel. While one of the generators is being charged or discharged the other can go on generating without interrupting the supply of gas. Should at any time the gas pressure exceed a certain amount, the dilute acid is forced up into the upper compartment through pipe P clear of the metal, so that the generation of gas ceases until the pressure becomes reduced. During the action of the acid on the metal heat is evolved which aids in the vaporisation of the oil in the carburetting vessel. 5

It will be obvious that when a continuous production of gas is not required, a single producer A may be employed in combination with the carburetting apparatus B in the manner described. 10

When generators of large capacity are required I prefer to make the acid chamber separate from those which contain the charges of iron.

By this means I am able to employ vessels of much simpler form, such as wooden tanks lined with lead or other material not liable to be attacked by the acid. 15

Figure 4 shews such an arrangement where A A are two vessels in which the charges of iron are decomposed, these vessels may be fitted with perforated bottom plate E, and openings are provided as before for the introduction of the charge and withdrawal of the residue, the necessary pipes and cocks also for connection with the acid chamber, which in this case is a simple vessel B placed preferably between and above vessels A A. 20

The latter are also provided with the necessary pipes and cocks for carrying off the gas and drawing off liquid.

Having now particularly described and ascertained the nature of this invention, and in what manner the same is to be performed, I declare that what I claim is:— 25

1. Apparatus for producing and carburetting hydrogen, consisting of a circular producer A with central filling tube D such apparatus being constructed and operating in combination with a carburetting apparatus B substantially as described with reference to the accompanying drawings. 30

2. Apparatus for the continuous production and carburetting of hydrogen consisting of two producers A and a carburetting apparatus B, constructed and operating substantially as described with reference to the accompanying drawings.

Dated this 13th day of August 1898.

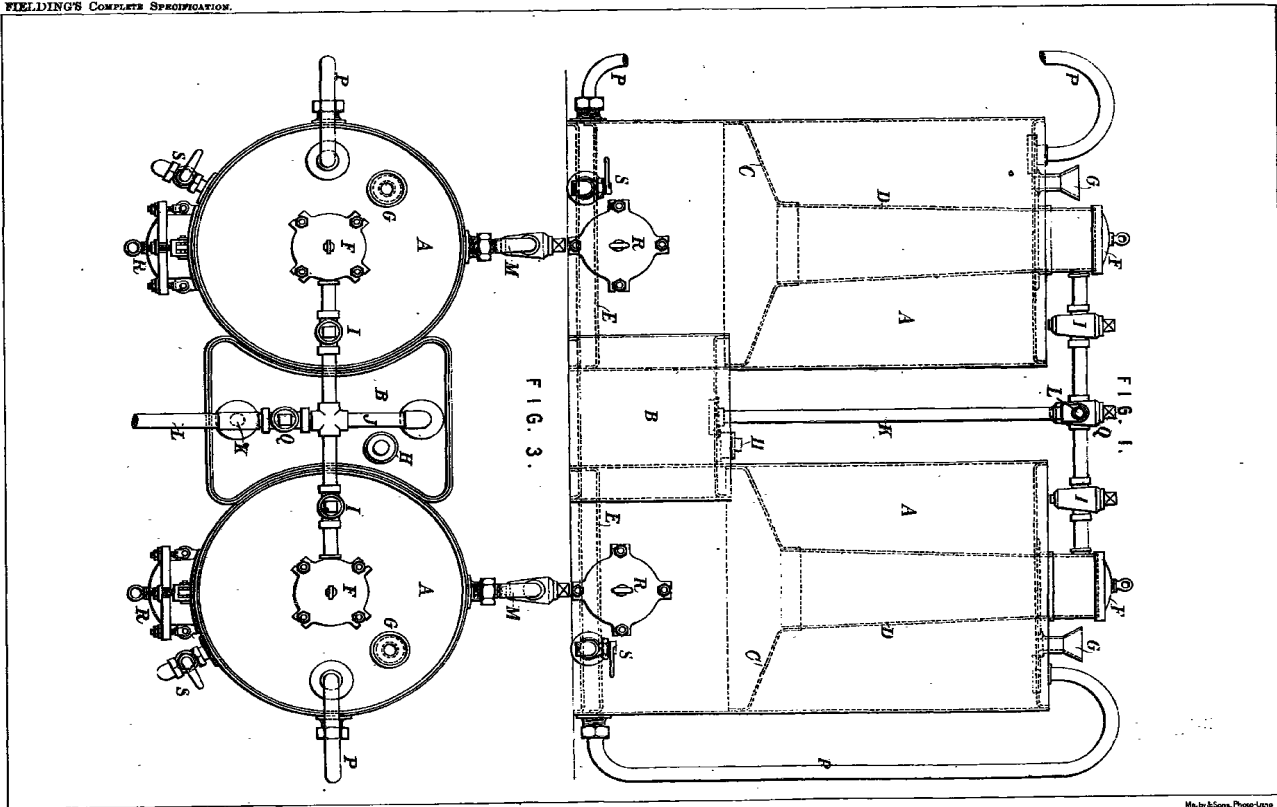
ABEL & IMRAY, 35  
Agents for the Applicant.

Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1898

A.D. 1898. Aug. 13. N<sup>o</sup> 17,516.  
FIELDING'S COMPLETE SPECIFICATION.

12 SHEETS;  
SHEET 1

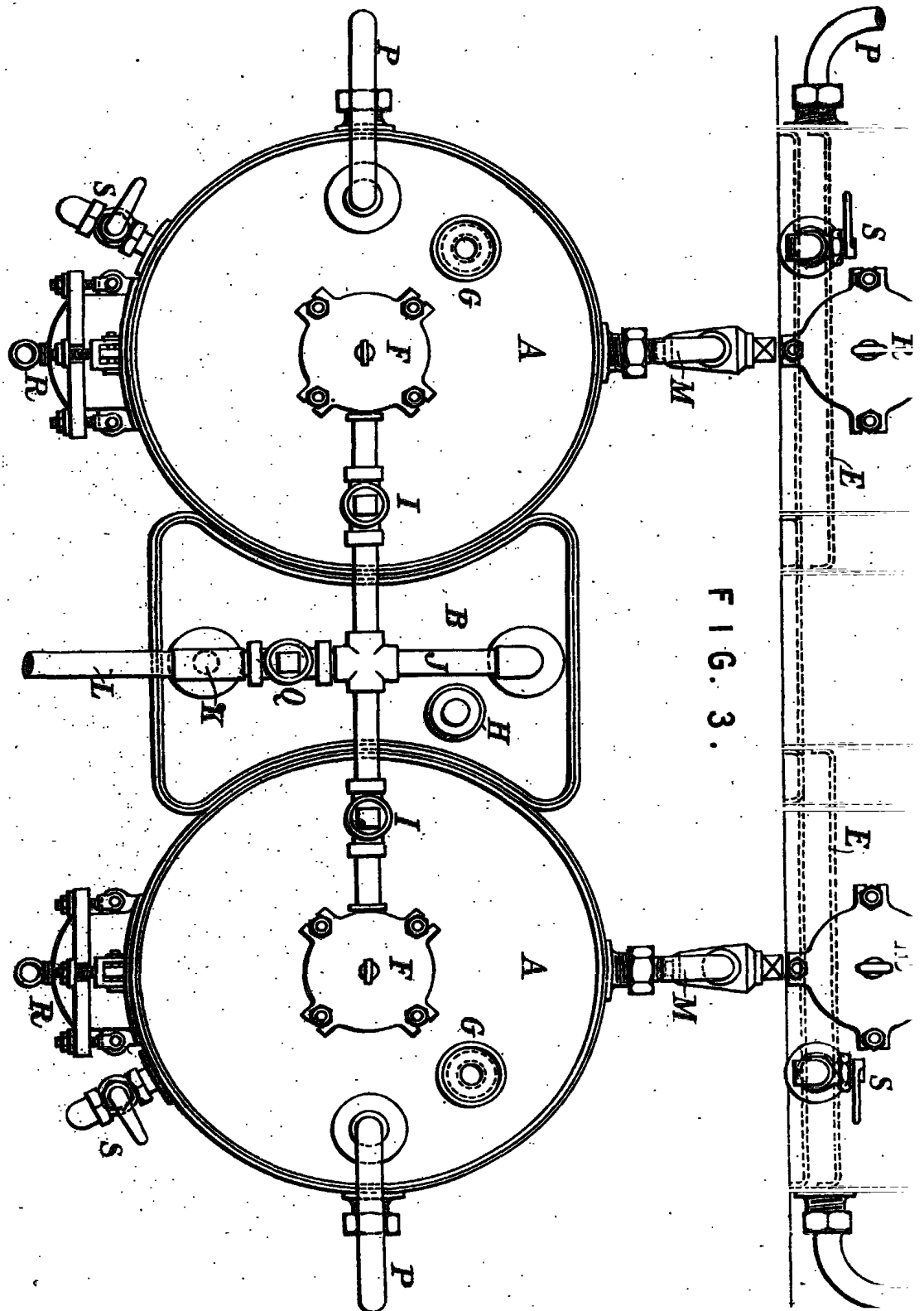
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M. J. S. Sons, Photo-Litho

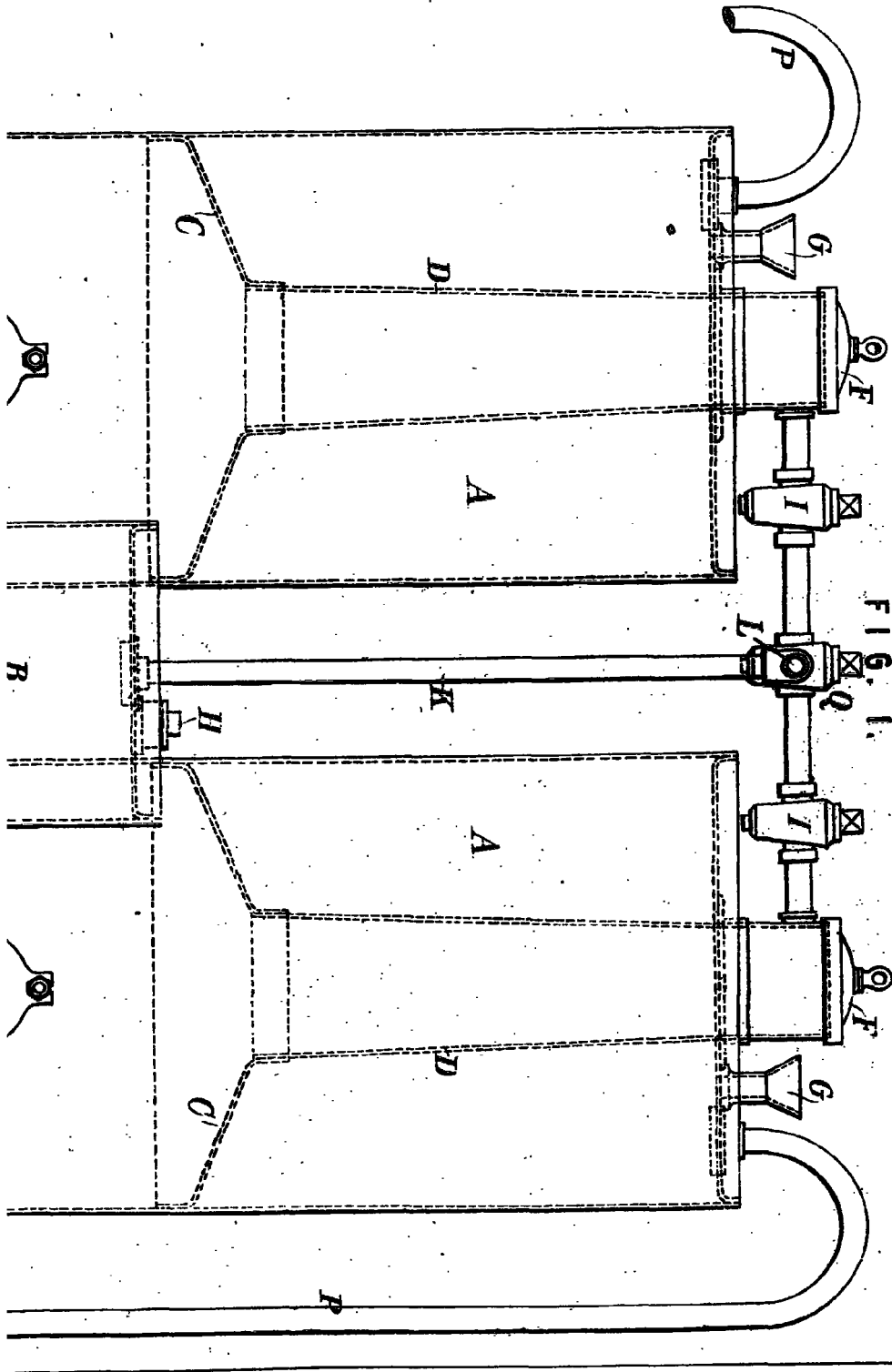
A.D. 1898. Aug. 13. N<sup>o</sup> 17,516.

FIELDING'S COMPLETE SPECIFICATION.



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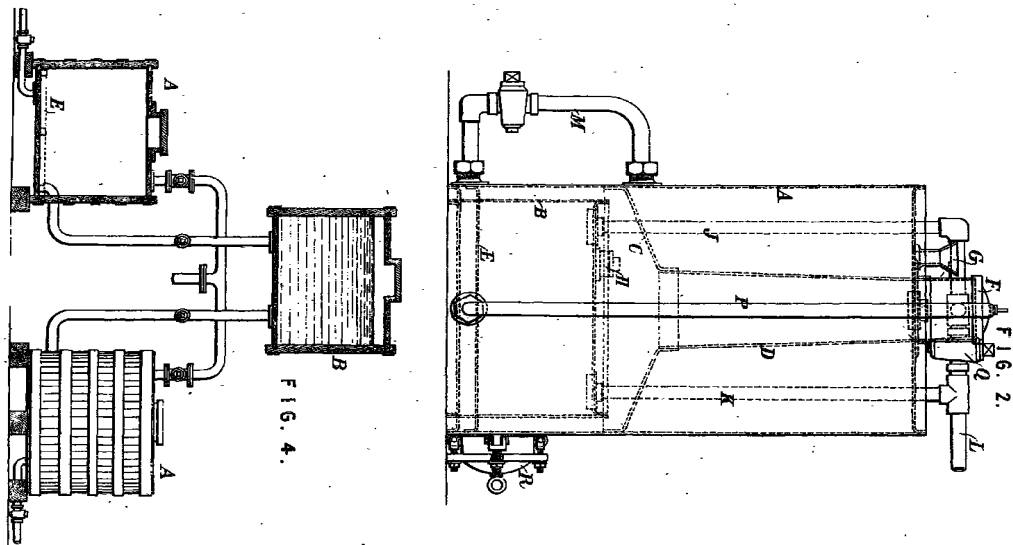
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Melby & Sons, Photo-Litho.

A.D. 1898, Aug. 13, N<sup>o</sup> 17,016.  
FIELDING'S COMPLETE SPECIFICATION.

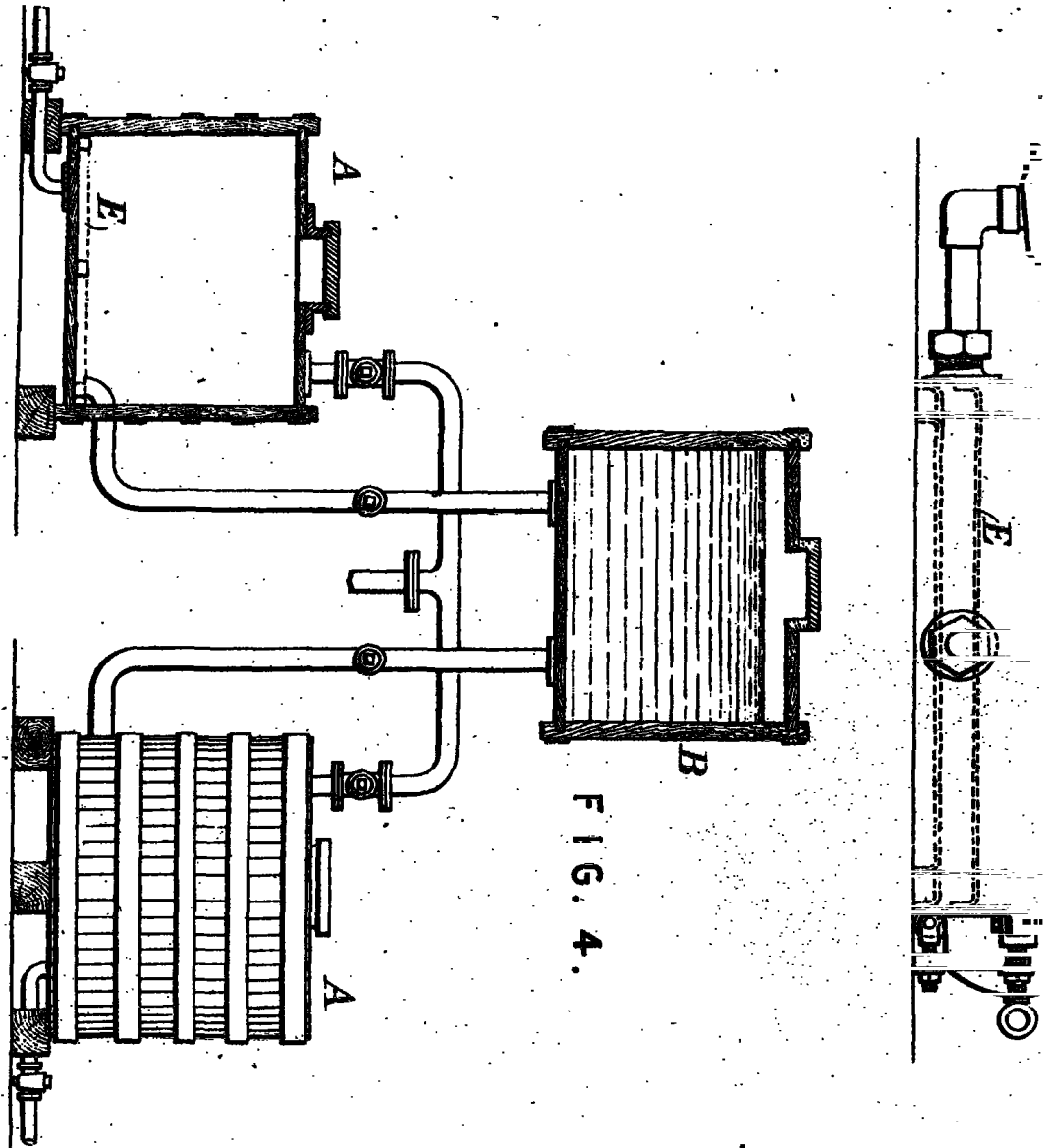
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SHEET 2.



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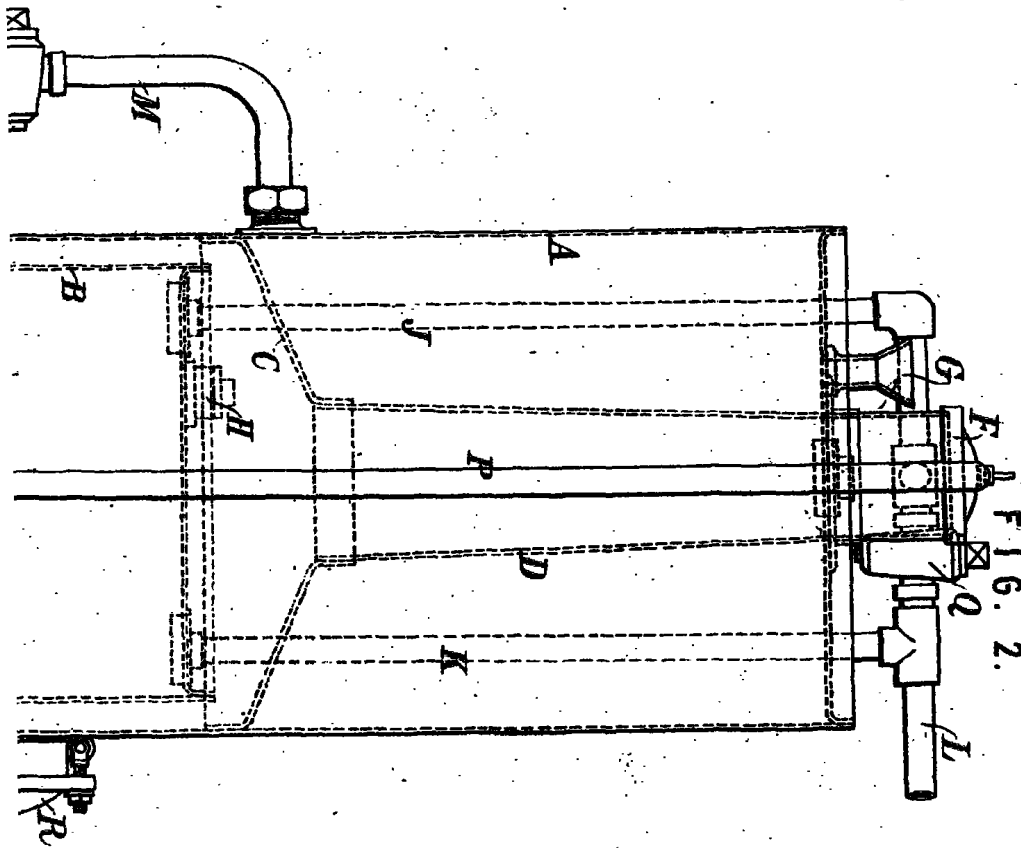
Mally & Sons, Printers-Lith.

A.D. 1898. AUG. 13. N: 17,516.  
FIELDING'S COMPLETE SPECIFICATION.



(2 SHEETS)  
SHEET 2.

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Malyby & Sons, Photo-Litho.



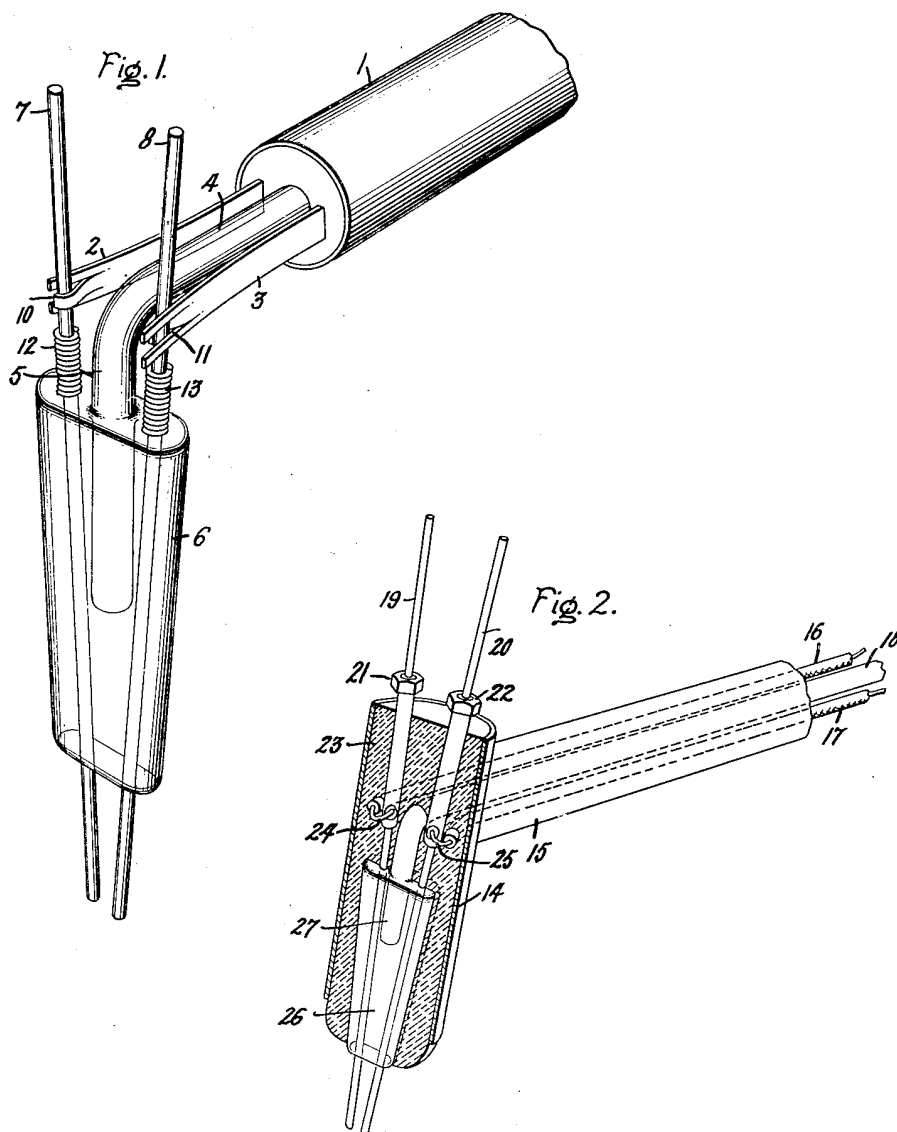
Dec. 8, 1931.

P. P. ALEXANDER

1,834,991

ATOMIC GAS TORCH

Filed Aug. 25, 1930



Inventor:  
Peter P. Alexander,  
by *Charles E. Tuller*  
His Attorney.

Patented Dec. 8, 1931

1,834,991

# UNITED STATES PATENT OFFICE

PETER P. ALEXANDER, OF MARBLEHEAD, MASSACHUSETTS, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK

## ATOMIC GAS TORCH

Application filed August 25, 1930. Serial No. 477,542.

My invention relates to gas-arc torches, and particularly to torches of this type adapted for cutting, welding, or other metallurgical operations employing atomic gases.

5 My invention is particularly applicable to the utilization of the heating effect of flames of atomic hydrogen. Utilization of such atomic hydrogen flames is disclosed and claimed broadly in the copending application  
10 of Irving Langmuir, Serial No. 729,185, filed July 30, 1924, for heating process and apparatus, which application is assigned to the same assignee as the present application. As disclosed in that application a flame of  
15 atomic gas is produced by supplying molecular gas to an arc where it is dissociated and conveying the dissociation products, i. e., atomic gas, from the arc to the place where it is to be utilized as a heating medium.

20 An object of my invention is to provide a torch in which the arrangement of parts is such that a single jet of gas may be employed for completely enveloping the arcing terminals of its electrodes.

25 A further object of my invention is to provide a torch in which the gas is supplied about the electrodes in such a manner as to prevent the entrainment of air in the gas supplied to and about the arcing terminals  
30 of the torch.

A further object of my invention is to provide a torch in which the electrodes are arranged in substantially parallel relationship with one another.

35 My invention will be better understood from the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

40 In the drawings Fig. 1 represents one embodiment of my invention, and Fig. 2 a modification thereof.

The torch illustrated in Fig. 1 comprises a handle 1 through which extend conductors  
45 2 and 3 and a conduit 4. Attached to the terminal 5 of the conduit 4 is a nozzle member 6. Electrodes 7 and 8 arranged substantially parallel to one another are supported in the walls of the nozzle 6 and extend there-  
50 through, their arcing terminals being located

a short distance from its discharge opening. The electrodes 7 and 8 are connected through clips 10 and 11 forming an integral part of conductors 2 and 3 to a source of power which in turn is connected through suitable conductors, not shown, to conductors 2 and 3. The  
55 longitudinal adjustment of the electrodes 7 and 8 in the nozzle 6 is controlled by spring clamps 12 and 13 located about the electrodes and engaging the upper exterior portion of the  
60 nozzle 6 through which the electrodes extend. Gas is supplied to the nozzle through the conduit 4 which terminates within nozzle 6. In the particular arrangement illustrated the terminal portion 5 of the conduit 4 extends  
65 into the nozzle 6 and is located centrally with respect to the electrodes 7 and 8. Gas is thus supplied from the conduit 4 in the form of a jet which is discharged between and along the length of the electrodes through the opening in the nozzle member through which  
70 these electrodes extend. The nozzle member 6 in the torch shown in the drawings is of oval shape so as to closely surround the electrodes 7 and 8. This construction is employed in order to secure economy in the  
75 consumption of gas. In the particular torch illustrated the nozzle member 6 is made of quartz, the conduit 4 of glass, and the electrodes 7 and 8 of tungsten.

80 By arranging the electrodes in substantially parallel relationship with one another, the gas supplied to their arcing terminals does not appreciably cool the molten tips of the electrodes, and the arc established therebetween consequently operates at a higher efficiency in generating atomic gas than would  
85 be the case if the electrodes were placed at an angle to one another. Furthermore, the particular manner in which the gas is supplied to and about the arcing terminals of the electrodes prevents the introduction of air at the point of welding as well as at the arcing  
90 terminals of the electrodes. The absence of all oxygen within the shielding gas, or in proximity to the atomic gas renders the torch particularly suitable for welding highly oxidizable metals such as aluminum, chromium, and alloys of these metals. Because of the absence of oxygen about the terminals of the  
95 100

2

1,834,991

electrodes, the consumption thereof is considerably less than in other torches where the manner of supplying the gas causes small quantities of oxygen to be entrained and supplied about the arc.

My torch is suitable for use with a single gas or mixtures of gases. I have found it particularly useful when using ammonia gas or mixtures of hydrogen and nitrogen. By employing the particular construction illustrated, it is possible to obtain a light-weight torch which is easy to manipulate and which supplies atomic gas with a minimum of discomfort to the operator. This is due to the fact that the torch operates with a small flame which is confined about the electrodes. In my torch a single jet of gas acts both as an enveloping agency and as a means for carrying the atomic gas from the arc to the point where it is to be employed as a heating medium.

Either direct or alternating current may be supplied to the electrodes. Multiphase alternating current may be used. When more than two electrodes are used the configuration of the discharge opening 9 should correspond to the spaced arrangement of the electrodes in order to secure the desired gas economy.

In Fig. 2 I have illustrated a modification of the arrangement shown in Fig. 1. In this figure the nozzle comprises a hollow member 14 attached to a shank 15 through which conductors 16, 17 and conduit 18 extend. The electrodes 19 and 20 are supported in the nozzle of the torch by means of holders 21 and 22. These holders are held in place within the member 14 by means of a refractory insulating cement 23. This construction by means of which the electrodes are supported in the hollow terminal member by electrode holders held in place therein by refractory means is described and claimed in the application of Boris Vasley Nagashev, Serial No. 477,508 for atomic gas torch, filed concurrently herewith, and assigned to the same assignee as the present application. Current is supplied to the electrodes through conductors 16 and 17 which are attached at 24 and 25 to the electrode holders 21 and 22. A chamber 26 is provided in the insulating material 23. The terminal portion 27 of conduit 18 extends into the upper portion of this chamber 26, the arrangement and proportion of parts being similar to that illustrated in Fig. 1.

Other modifications of my improved torch will occur to those skilled in the art, in view of the arrangements above described. While I have shown and described certain particular embodiments of my invention, such variations and modifications are contemplated as fall within the spirit and scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A gas-arc torch comprising a plurality of electrodes, means for holding said electrodes in substantially parallel relationship with one another, means for insulating said electrodes from one another, means for supplying to the arcing terminals of said electrodes and along their length a single jet of gas completely enveloping said electrodes, and means for supplying an electric current to said electrodes.

2. A gas-arc torch comprising a nozzle member, means for holding a plurality of electrodes in substantially parallel positions in said nozzle member with their arcing terminals projecting a short distance beyond the discharge opening of said nozzle member, means for supplying gas to said nozzle member, and means for supplying an electric current to said electrodes.

3. A gas-arc torch comprising a nozzle member, a plurality of electrodes, means for holding said electrodes in substantially parallel relationship with one another in said nozzle member with their arcing terminals projecting a short distance beyond the discharge opening of said nozzle member, means in the upper portion of said nozzle member for discharging a jet of gas between and along the length of said electrodes, through the opening in said nozzle member, and means for supplying an electric current to said electrodes.

4. A gas-arc torch comprising a plurality of substantially parallel electrodes, means for insulating said electrodes from one another, a chamber through which said electrodes project, a discharge opening in said chamber near the arcing terminals of said electrodes having a configuration corresponding to the spaced arrangement of said electrodes, means for discharging a jet of gas in said chamber through the opening in said chamber and across the arcing terminals of said electrodes, and means for supplying an electric current to said electrodes.

In witness whereof I have hereunto set my hand this 21st day of August, 1930.

PETER P. ALEXANDER.

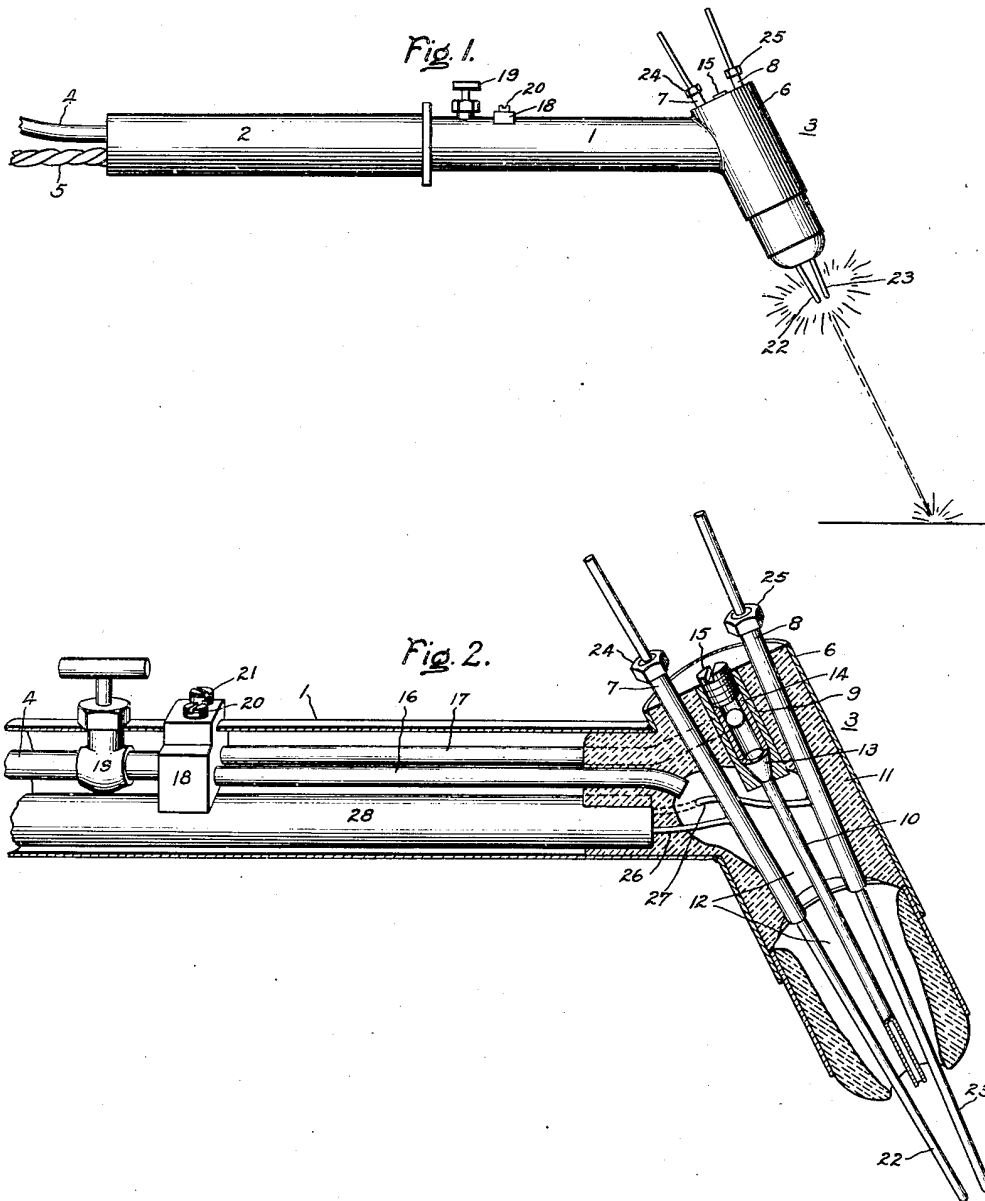
May 23, 1933.

B. V. NAGASHEV

1,911,033

ATOMIC GAS TORCH

Filed Aug. 25, 1930



Inventor:  
Boris V. Nagashev,  
by *Charles E. Zeller*  
His Attorney.

Patented May 23, 1933

1,911,033

## UNITED STATES PATENT OFFICE

BORIS VASLEY NAGASHEV, OF LYNN, MASSACHUSETTS, ASSIGNOR TO GENERAL  
ELECTRIC COMPANY, A CORPORATION OF NEW YORK

## ATOMIC GAS TORCH

Application filed August 25, 1930. Serial No. 477,508.

My invention relates to atomic gas torches, and particularly to torches of the gas-arc type adapted for cutting, welding, spraying metals, or for other metallurgical operations.

5 My invention is particularly applicable to the utilization of the heating effect of flames of atomic hydrogen. Utilization of such atomic hydrogen flames is disclosed and claimed broadly in the copending applica-  
10 tion of Irving Langmuir, Serial No. 729,185, filed July 30, 1924, for Heating process and apparatus, which application is assigned to the same assignee as the present application. As disclosed in that application a flame of  
15 atomic gas is produced by supplying a molecular gas to an arc where it is dissociated and conveying the dissociation products, i. e. atomic gas, from the arc to the place where it is to be utilized as a heating medium. In  
20 one particular embodiment described in that case a jet of gas is directed across the arc to carry the atomic gas generated in the presence of the arc to the object to be heated.

25 I have found that a blast of a large amount of hydrogen will cool off the atomic gas so appreciably that it will recombine into its molecular state at a comparatively short distance from the arc core. If in place of a tube of appreciable cross-section a capillary tube  
30 or tube of small bore be employed and gas supplied through this tube under substantial pressure, the gas issuing from the tube will have sufficient velocity to draw the atomic  
35 gases about the arc into a narrow pencil, and the amount of gas used in the jet will be so small that it will not appreciably cool off the arc core or the gases surrounding it. Since  
40 the temperature of the gases is not appreciably lowered by this latter procedure the atomic gas does not recombine into its molecular state for an appreciable interval of time. Consequently, by employing capillary  
45 tubes or tubes of small bore for discharging a fine jet of high velocity gas across the arc, it is possible to produce a long flame of atomic gas.

50 It is an object of my invention to provide a torch in which a tube of small bore is used for directing a fine jet of high velocity gas

across the arcing terminals of electrodes about which atomic gas is generated.

It is a further object of my invention to provide in a gas-arc torch means for drawing the atomic gas generated about the arc  
55 into a long, narrow, concentrated stream suitable for performing heating operations at substantial distances from the torch.

My invention will be better understood from the following description taken in connection with the accompanying drawing and  
60 its scope will be pointed out in the appended claims.

In the drawing Fig. 1 is a side view of one embodiment of my improved torch in which  
65 the nature and length of the atomic gas flame has been indicated, and Fig. 2 is a sectional view of the head of the torch shown in Fig. 1 showing the construction and arrangement  
70 of the parts thereof.

The torch shown in Fig. 1 comprises a stock 1 provided at its left end with a handle 2 and at its right end with a head member 3 constituting the nozzle of the torch. Gas is  
75 supplied to the torch through a conduit 4 and electricity, through conductors 5.

The head 3 of the torch comprises, as shown in Fig. 2, a hollow member 6 enclosing a plurality of electrode holders 7 and 8, a bushing 9, and a tube 10. The electrode holders 7 and  
80 8 and bushing 9 are held in place within the hollow member 6 by means of a refractory, insulating cement 11, the arrangement of parts being such that electrodes inserted in the electrode holders will be substantially  
85 parallel to one another and to the tube 10 supported in the bushing 9. A chamber 12 is formed in the cement 11 and the electrode holders 7 and 8 and the tube 10 extend into this chamber. The arrangement of the elec-  
90 trode holders is such that electrodes inserted therein extend through this chamber and beyond the head of the torch a slight distance, where the terminals of the electrodes approach within arcing distance of one another.  
95 The tube 10 extends to the tip of the torch terminating near the arcing terminal of the electrodes. This tube is of small bore and preferably of quartz formed with a tapered end portion 13 adapted to fit in a correspond-  
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ingly tapered portion of the bushing 9. The tube 10 is held in place in the bushing 9 by means of a hollow collar 14 and a set screw 15. By removing the set screw 15 and the collar 14, the tube 10 may be removed from the torch and renewed in case of breakage.

Gas is supplied to the upper portion of the chamber 12 through a tube 16 and to the interior of the bushing 9 through a tube 17. Tubes 16 and 17 are connected through a valve block 18 and a valve 19 to the conduit 4 through which gas is supplied to the torch. The valve block 18 is provided with two valves 20 and 21 by means of which the relative gas pressures in the pipes 16 and 17 are controlled. The valve 20 controlling the supply of gas through the tube 16 to the upper portion of the chamber 12 is sufficiently closed, so that gas under slight pressure is admitted into the upper portion of this chamber. Valve 21 which controls the supply of gas through tube 17, bushing 9 and tube 10 is opened to a greater extent so that high pressure gas is discharged through the small bore tube 10 and across the arcing terminals of the electrodes 22 and 23.

Electrodes 22 and 23 are clamped in the holders 7 and 8 by means of nuts 24 and 25. Current is supplied to these electrodes through conductors 26 and 27 attached to the holders 7 and 8. Either direct or alternating current, single or multiphase, may be used. These conductors are threaded through a porcelain bushing 28 which, together with the tubes 16 and 17, valve 19 and valve block 18, are enclosed within the stock 1 of the torch. Conductors 26 and 27 are connected with or are a continuation of the conductors 5 illustrated in Fig. 1. As shown in Fig. 2, the refractory insulating cement 11 is forced into the right-hand portion of the stock 1 and serves as a support for the ends of tubes 16 and 17 and the end of the porcelain bushing 28.

The method of operating the torch is as follows: Electrodes 22 and 23 are adjusted in holders 7 and 8 so that their terminals approach within arcing distance of one another. Gas, for example hydrogen, is then supplied to the chamber 12 and to the capillary tube 10 by opening the valve 19. An arc is then struck between the electrodes by completing a circuit therethrough through the agency of some conductor, and the torch then operates to generate atomic hydrogen which may be used for any desired metallurgical operation.

A bathing atmosphere is provided about the electrodes and the arc by the gas supplied through tube 16 into the upper portion of chamber 12. Atomic gas is blown out from between the electrodes by means of the high velocity gas jet issuing from the capillary tube 10. In the particular torch illustrated in the drawing the outside diameter of the quartz tube is about  $\frac{1}{8}$  of an inch and the

inside diameter about 20 mils. The gas pressure in front of the quartz tube may vary from one-half to 65 pounds per square inch according to the size of the flame and the current in the arc. The pressure of the shielding gas issuing from chamber 12 is a small fraction of an ounce, probably one-hundredth of one-tenth of an ounce.

The size of the tube 10 and the pressure of the gas used may vary considerably with the size of the torch and the character of the work. The underlying idea is to produce a blast of high velocity and yet not consume an excessive amount of gas. If the opening in the inner tube were large, it would have to admit such a large amount of gas that the arc as well as the flame beyond it would be cooled considerably. Under such conditions it would be impossible to maintain the conditions which are quite essential to keep the hydrogen in the atomic state. With the arrangement illustrated and described, however, a comparatively small amount of gas is blown either through or near the arc. This small amount of molecular hydrogen determines a draft so that the atomic hydrogen diffusing from the arc core is drawn, concentrated and directed in a narrow stream away from the arc.

The parallel arrangement of the electrodes, although not essential to my invention, is preferred for it further facilitates the copious generation of atomic hydrogen. By arranging the electrodes in substantially parallel relation, as illustrated, the molten tips of the electrodes, at the terminals of the arc established therebetween are not cooled by the blast of hydrogen issuing from the capillary tube 10. This results in a more stable arc and the generation of a greater amount of atomic hydrogen than would result if the electrodes were located at a substantial angle to one another. The parallel arrangement of the electrodes in the compact structure made possible by this arrangement also greatly reduces the size of the head of the torch and renders it suitable for use in congested places where the amount of clearance is small. The parallel arrangement of welding electrodes in a gas-arc torch forms part of the subject matter of the application of Peter P. Alexander, Serial No. 477, 542, for Atomic gas torch, filed concurrently herewith, and assigned to the same assignee as the present application.

Because of the long pointed flame produced by my improved torch, it is possible to perform welding operations in otherwise inaccessible places. I have been able with the torch illustrated and described to render incandescent a refractory brick at a distance of six and a half inches from the torch, and the concentrated stream of gas will give a flame extending from six to eight inches from the arc maintained between the terminals of

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the electrodes 22 and 23. The atomic flame generated by my torch is quite similar to the oxy-hydrogen flame in shape and stiffness, although much hotter than the same.

5 Because of the possibility of holding the torch at a considerable distance from the work the electrodes and torch will be kept far enough away from the pool of molten metal in the work so as not to become contaminated by metallic particles projected from the pool during welding. Further-  
10 more, the torch can be held at a sufficient distance from the work so that the arc established between the electrodes does not come in contact therewith and become shorted during the welding operation.

Because of the small amount of hydrogen used and the confined and directive nature of the flame, my torch may be used by operators  
20 more comfortably than previous designs in which the atomic flame has not been so well confined and directed. The long pointed flame likewise renders the torch suitable for cutting operations. The flame both melts  
25 the metal to be cut and blows the molten metal from the kerf.

While I prefer to employ my torch for atomic hydrogen welding and cutting, it may be used with other gases than hydrogen and  
30 for performing other operations than welding and cutting. Mixtures of gases may be used instead of pure gases and the decomposition products of gases and liquids such as ammonia and methanol may be used.

35 While I have illustrated a torch provided with a handle for manual operations, it is apparent that the torch may be mounted in an automatic machine.

What I claim as new and desire to secure  
40 by Letters Patent of the United States, is:

1. A nozzle for a gas-arc torch comprising a hollow member, a plurality of electrode holders, refractory insulating cement for supporting said holders and for forming in  
45 said member a chamber into which electrodes supported by said holders project, and means for supplying gas to the upper portion of said chamber.

2. A gas-arc torch comprising means for  
50 holding a plurality of electrodes in adjusted relation relatively to one another, a chamber through which said electrodes extend, a conduit terminating in the upper part of said chamber for supplying gas thereto, and  
55 a second conduit extending through said chamber and arranged to direct a blast of gas between the arcing terminals of electrodes inserted in said holders.

3. A gas-arc torch comprising means for  
60 holding a plurality of electrodes in adjusted relation relatively to one another, a chamber through which said electrodes extend, a conduit terminating in the upper part of said chamber for supplying gas thereto, and  
65 means for producing across the arcing ter-

minals of electrodes inserted in said holders a small jet of high velocity gas.

4. A gas-arc torch comprising means for holding a plurality of electrodes in adjusted relation relatively to one another, a plurality  
70 of electrical conductors, means for independently connecting one of said conductors to each of said holders, refractory electrical insulating means for supporting said electrode holders, a chamber in said refractory  
75 insulating means into which said electrode holders extend, a conduit extending into the upper portion of said chamber, and a second conduit extending through said chamber and terminating near the arcing terminals of  
80 electrodes supported in said holders.

5. A torch comprising a nozzle member, means in said member for holding a plurality of electrodes in adjusted relation relatively to one another, means for insulating said holding means from one another, a plurality of insulated electrical conductors, means for independently connecting one of said conductors to each of said holders, a capillary tube in said nozzle extending therethrough and terminating in proximity to the arcing terminals of electrodes inserted in said holders, means for supplying gas to said nozzle member, means for supplying gas to said capillary tube, and means for controlling the supply of gas to said nozzle and to said capillary tube.

6. A torch comprising a hollow terminal member, a plurality of electrode holders in said member for holding a plurality of electrodes in substantially parallel relationship with one another and with their arcing terminals extending beyond said member, a plurality of electrical conductors and pipes extending into said member, refractory insulating means for supporting said electrode holders and the terminal portions of said pipes and conductors, a chamber in said refractory insulating means into which said electrode holders, pipes and conductors extend, means for independently connecting one of said conductors to each of said electrode holders, a capillary tube in said chamber extending therethrough in substantially parallel relationship with said holders and terminating near the arcing terminals of electrodes inserted in said holders, and means for connecting said tube to the terminals of one of said pipes.

7. A gas-arc torch comprising a plurality  
120 of electrode holders, a plurality of electrical conductors, means for independently connecting one of said conductors to each of said electrode holders, a tube of refractory material, a bushing, means for detachably clamping said tube in said bushing, refractory insulating means for supporting said electrode holders and said bushing and for positioning thereby the discharge opening of said tube clamped in said bushing in  
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proximity to the arcing terminals of electrodes inserted in said electrode holders, a chamber in said refractory insulating means into which said electrode holders and said  
5 bushing extend, a conduit extending into the upper portion of said chamber, and a second conduit terminating in said bushing.

In witness whereof, I have hereto set my hand this 22nd day of August, 1930.

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**BORIS VASLEY NAGASHEV.**

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# United States Patent [19]

**Brown**

[11] **4,014,777**  
[45] **Mar. 29, 1977**

[54] **WELDING**

[76] Inventor: **Yull Brown**, 182 Auburn Road,  
Auburn, New South Wales,  
Australia

[22] Filed: **July 19, 1974**

[21] Appl. No.: **489,921**

[30] **Foreign Application Priority Data**

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May 2, 1974 Australia ..... 7418/73  
Aug. 3, 1973 Australia ..... 4341/73

[52] U.S. Cl. .... **204/270; 429/21;**  
204/129; 204/228; 204/229; 204/268;  
204/269; 204/272; 431/354

[51] Int. Cl.<sup>2</sup> ..... **C25B 1/02; C25B 1/04**

[58] Field of Search ..... 204/129, 270, 278, 228,  
204/230, 237, 269, 229, 272, 271; 136/86 R;  
55/3, 100; 29/498.5; 219/137; 431/354;  
206/7

[56] **References Cited****UNITED STATES PATENTS**

685,274 10/1901 Haas ..... 204/268  
1,600,478 9/1926 Lawaczek ..... 204/272 X

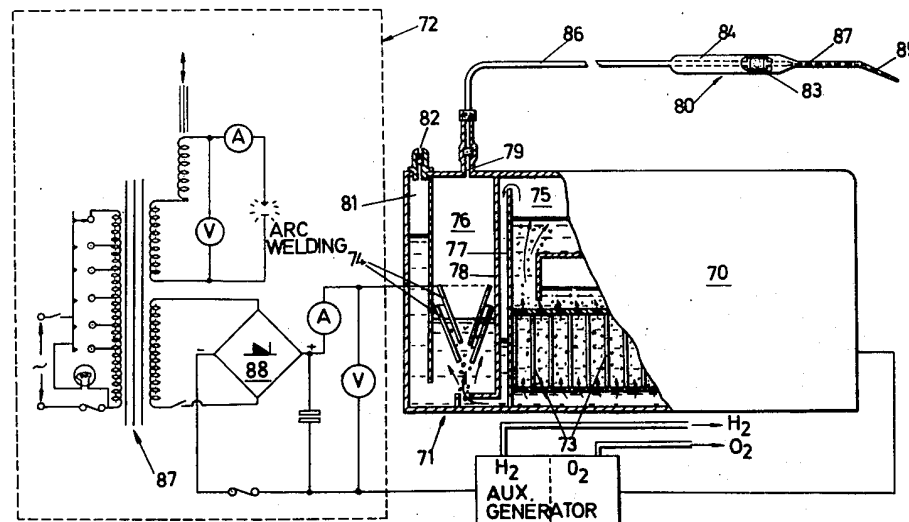
3,045,665 7/1962 Movat ..... 204/129 X  
3,177,633 4/1965 McDonald, Jr. .... 55/3 X  
3,262,872 7/1966 Rhodes et al. .... 204/129 X  
3,310,483 3/1967 Rhodes ..... 204/129 X

*Primary Examiner*—Arthur C. Prescott  
*Attorney, Agent, or Firm*—Hill, Gross, Simpson, Van  
Santen, Steadman, Chiara & Simpson

[57] **ABSTRACT**

This invention relates to welding, brazing or the like utilizing a mixture of hydrogen and oxygen generated in substantially stoichiometric proportions in an electrolytic cell by electrolytic dissociation of water, the mixture so generated being passed from the generator through a flash-back arrestor and thence to a burner where the gases are ignited. The invention also relates to atomic welding in which the above mentioned mixture is passed through an arc causing dissociation of both the hydrogen and oxygen into atomic hydrogen and oxygen which on recombination generate an intensely hot flame.

**6 Claims, 7 Drawing Figures**



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FIG. 1.

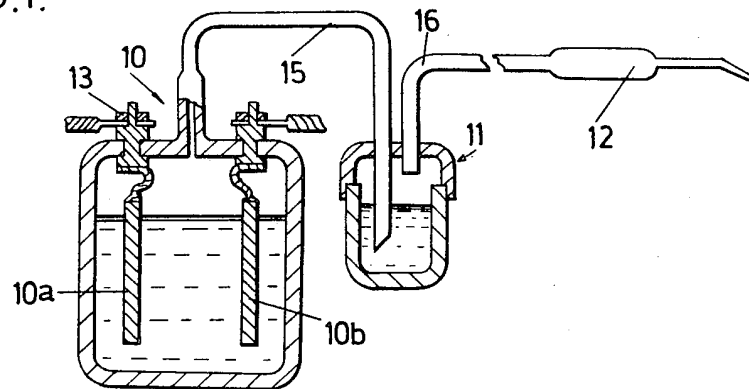
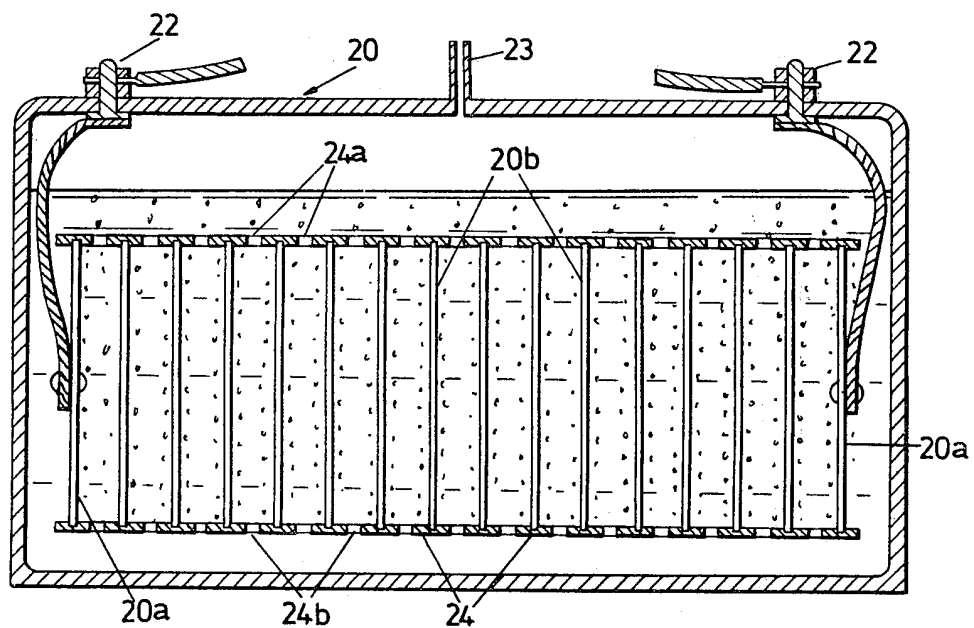


FIG. 2.



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FIG. 3.

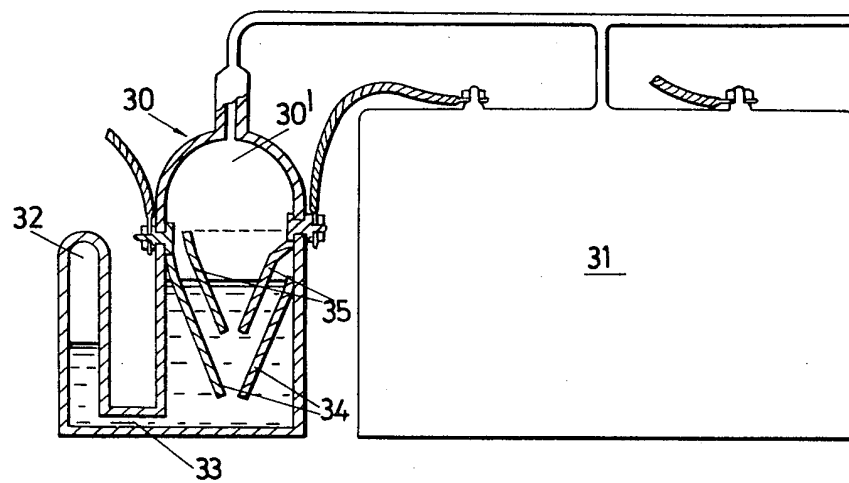
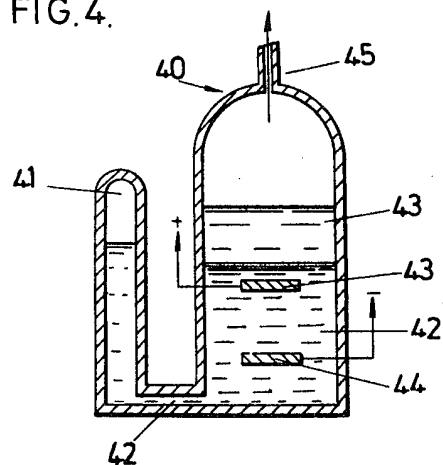


FIG. 4.



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FIG. 5.

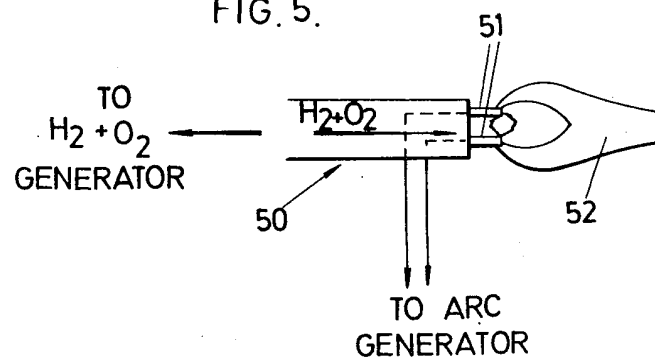
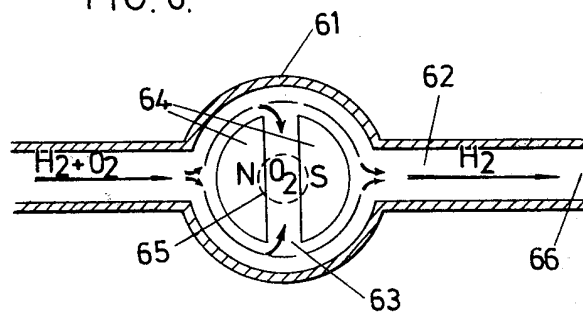


FIG. 6.

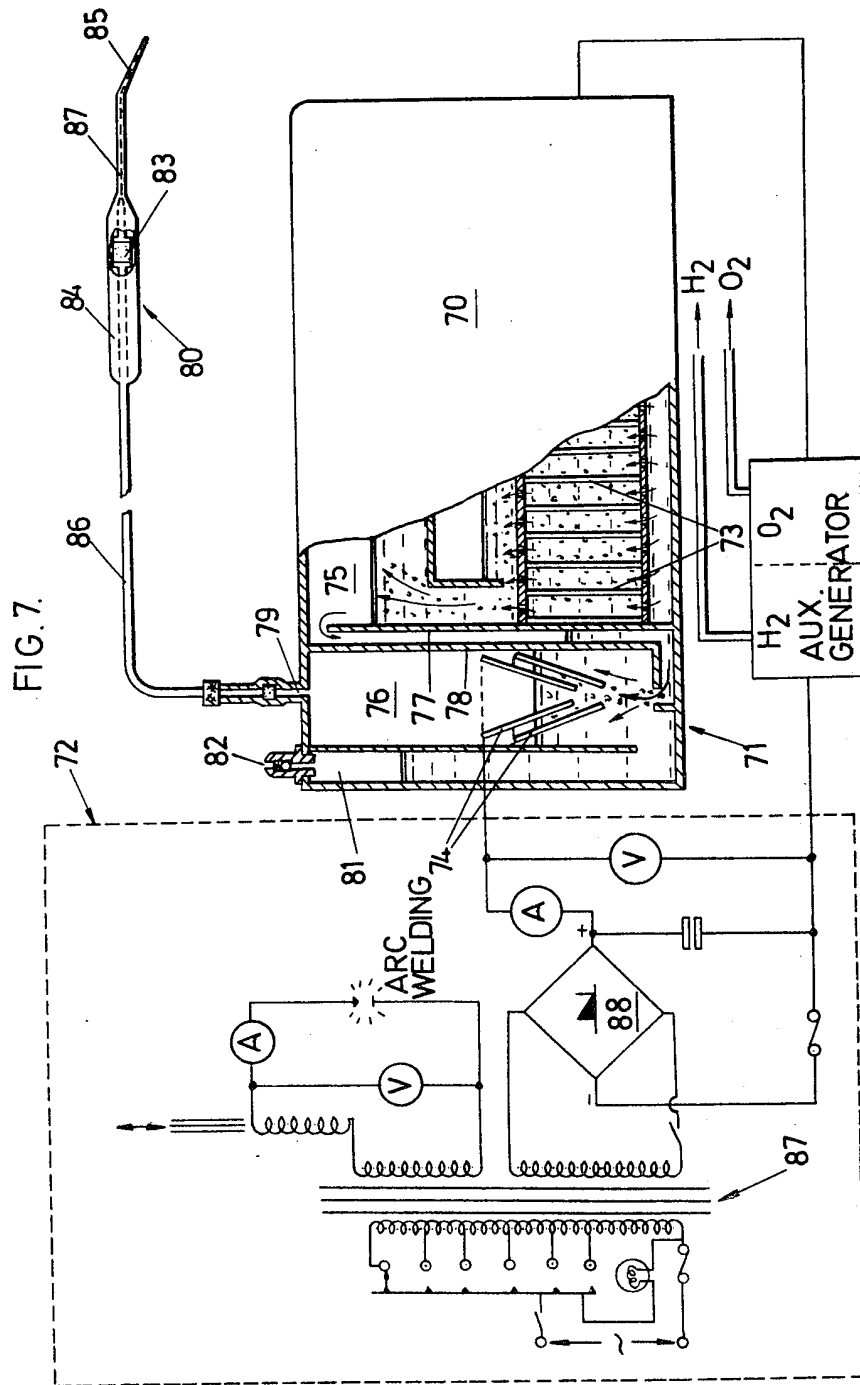


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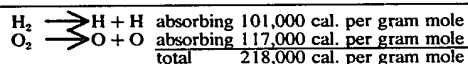
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## WELDING

This invention relates to welding, brazing and the like, utilizing hydrogen and oxygen, and extends to such applications as oxy-welding, oxy-cutting, atomic welding, and welding or cutting in combination with electric arc techniques. The invention also provides for the generation of hydrogen and oxygen for the above-mentioned applications in combination therewith or separately.

A most important application of the invention is atomic welding utilizing the properties of atomic oxygen in combination with atomic hydrogen (for welding) or atomic oxygen separately (for cutting). This particular application of the invention is based, among other things, on the appreciation that considerable energy is associated with the dissociation of molecular oxygen into atomic oxygen by passing this gas through an arc, and that this property can be usefully employed to generate temperatures even higher than those previously attainable with, for example, an atomic hydrogen flame. The significance of the energy which can be obtained in this way can be appreciated from the following reactions that take place, and the heat energies associated therewith, when hydrogen and oxygen are both passed through an electric arc. Thus:



On recombination of these atoms this energy is released as heat through a number of complex chemical reactions and results in an extremely high flame temperature. Previously it would not have been considered possible to practically pass oxygen or a mixture of oxygen and hydrogen together through an arc due to the highly explosive or inflammable nature of such gases. However in accordance with the concepts of the present invention this is indeed both possible and practical and, as mentioned above, enables the realization of much higher welding or cutting temperatures than hitherto obtainable by known practical means.

One of the objects of the present invention is to provide a method and apparatus whereby hydrogen and oxygen can be generated quickly and conveniently for immediate use for welding, etc., without many of the disadvantages associated with conventional gas welding practice. For example, the practice of employing cylinders (or "bottles") of gas, usually oxygen and acetylene can have significant disadvantages, particularly for users working remote from a supply depot and for whom there might be an appreciable delay between the placing of an order for a delivery of gas the the actual delivery. For such users, in order to ensure an adequate supply of gas when a particular job demands it, it is often necessary to order fresh supplies in advance, even before the supply on hand is fully used, or else risk running out of gas before a job is completed. Since bottles of gas are generally delivered on a strictly exchange basis — in that a used bottle must be returned in exchange for a refilled bottle — the practice can mean a significant waste, as far as the user is concerned, if bottles containing useful amounts of unused gas have to be returned to the supplier.

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The practice of using bottled gas also has associated with it a large number of other problems such as the possibility of gas leaking from bottles, possibility of industrial disputes which can result in severe delays in delivery and in supply shortages, liabilities, high purchase and storage costs, freight charges, and so on.

To illustrate some of the conditions which the consumer of bottled gas must put up with, listed below is a summary of the "conditions of sale" which apply to the sale and distribution of bottled gas.

a. The cylinder remains the sole property of the supplier, which retains the right to exercise at any time its proprietary powers in its discretion.

b. All cylinders and contents are forwarded at the expense and risk of the customers.

c. It is the responsibility of the customers to provide adequate labour for the loading and unloading of all cylinders at the premises.

d. Cylinders are to be returned to the supplier as soon as empty, carriage and freight charges paid.

e. A cylinder is not 'returned' until received by the supplier at its works or warehouse or by its truck and a receipt on the suppliers form given for the same. No document purporting to be a receipt for any such cylinder shall be valid unless it is the suppliers printed form of receipt.

f. Cylinders are not transferable and must not be used for any purpose other than as containers for the gas sold by the supplier and must not be delivered or sent for recharging to any place other than the suppliers gas station.

g. The customer agrees not to resell to any person or Corporation, the gas contents of the cylinders of any part thereof.

h. Customers are held responsible for all loss or damage to cylinders from whatever cause arising from the time of delivery until returned to the suppliers. (Customers are advised to cover the cylinders by insurance).

i. Where a customer has not returned a cylinder in good order and condition within six months from the date of delivery, the supplier may, at its option, charge the customer with an amount not exceeding the agreed value of the cylinder and the demurrage due in respect thereof, and such amount is payable by the customer as liquidated damages for the detention of the cylinder. Notwithstanding the payment of such amount in respect of any cylinder, it remains the property of the suppliers and the right of the suppliers to recover possession thereof is not affected in any way.

j. No allowance is made on any residual gas returned in the cylinders.

k. And many other conditions varying in the different countries in the world.

Another disadvantage, which is associated with oxy-hydrogen welding arises due to the marked ability of hydrogen to be absorbed by most metals. Thus when welding steel, for example, great care must be taken to ensure that excess hydrogen is not present otherwise it will be absorbed in the metal to cause loss of strength and brittleness. On the other hand, an excess of oxygen would cause burning of the metal and should thus equally be avoided. It is most important therefore that with oxy-hydrogen welding the mixture at the burner be adjusted to produce a neutral flame, that is, one in which there is neither excess hydrogen nor excess oxygen. In practice it is most difficult to maintain (and virtually impossible to judge by flame colour) a neutral

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flame, and for that reason oxy-hydrogen welding is not widely used despite the inherent advantages of low cost and high heat value offered by hydrogen as a fuel.

These and other disadvantages can be overcome to a significant extent by the present invention whereby hydrogen and oxygen fuel are generated simultaneously by electrolysis in an electrolytic cell and allowed to freely mix therein to form a stoichiometric mixture that will burn with a neutral flame. The fuel gas can be generated where and whenever required thereby eliminating the need for storage of bottles of gas and reliance on regular deliveries of gas which often cannot be guaranteed.

The method of the present invention requires no diaphragms or the like to separate the hydrogen and oxygen liberated by the electrolysis process and thereby enables considerable advantages to be realized over conventional electrolytic production of these gases. Such diaphragms have normally been regarded as essential for conventional electrolytic generators in order to separate the two gases that would otherwise form a highly explosive mixture; however, it has been found, in accordance with the present invention, that the two gases can be safely, and usefully, produced and utilized as a mixture for fuel purposes provided that suitable safety precautions, such as the employment of a flash-back arrestor, are taken. Such safety precautions may include, for example, the employment of a device which removes electrolyte vapour from the gas and at the same time acts as a flash-back arrestor. In obviating the need for diaphragms or the like the present invention enables the electrodes to be placed much closer together and avoids the high resistance associated with diaphragms, which in turn enables a significant increase in the rate of gas production for a given size of apparatus. In short the present invention enables the manufacture of small size equipment that is useful for a large variety of welding and similar work and that is not prohibitively bulky for the average situation: something which is impossible with conventional hydrogen-oxygen generating equipment.

In the development of apparatus from the basic concept of generation of hydrogen and oxygen electrolytically in a practical manner suitable for large industrial applications on the one hand, and small domestic applications on the other hand, a number of factors had to be taken into account, analysed and weighed one against the other. The following is a list of some of these factors to illustrate what has been involved.

a. Endosmotic pressure to be balanced against the hydrostatic pressure of the fluid.

b. Rate of flow of electric current in relation to the area of the electrodes.

c. The prior art problem of removing the gases from anolyte and catholyte, before diffusion and before the electrolytes are intermixed.

d. Effects of rapid changes in the rate of flow of electricity through the cell.

e. Effects of auxiliary decomposition within the anode and cathode sides of the cell.

f. The choice of the most readily ionized electrolyte of a maximum conductivity.

g. The least possible spacing between anode and cathode that can be employed.

h. A design of cell in which previously it was regarded impossible for the  $H_2$  and  $O_2$  given to become mixed with safety, which does away with diaphragms or the like which would increase the internal resistance, in

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which both hydrogen and oxygen can be mixed within the cell, and in which cells can be connected in series, parallel, or parallel and series to suit requirements.

i. The choice of materials for the electrodes.

j. The quantity of acids or alkali to be used.

k. The shapes of cells according to purpose of the cells, and the application for which they are designed.

l. The possibility of improvement with permanent or electro-magnetically induced fields applied to the electrolytic cells, to cause controlled separation of a quantity of the gases generated in the cells.

m. Ensuring effective circulation of electrolyte between the electrodes, with as little electrical resistance as possible.

n. The possibility of using sodium hydroxide or potassium hydroxide which, in concentrations from 10% up to 30%, which has negligible corrosion action on iron or nickel electrodes, apart from producing a solution of good conductivity.

o. The use of the cooling effect by passing of hydrogen and oxygen gases, for cooling electrolyte in the cell, for controlling the cell temperature, preferably between 40° C to 60° C, at which temperature the bonds between hydrogen and oxygen need a minimum of electrical energy to break.

p. The separation of hydrogen and oxygen from a mixture, using, possibly, a permanent magnetic field, or an electro-magnetic field which can be controlled to obtain a desired separation between the hydrogen and oxygen. Based on this principle, the oxygen could be substantially separated from the mixture and the hydrogen could be absorbed by, for example, selected metals, which have high absorption affinity for hydrogen (for example, palladium which absorbs 900 times more hydrogen from its volume). Also, using the principle of the invention, hydrogen and oxygen can be generated in large quantities with small units and the oxygen could, for example, be separated and used to supply hospitals, baby rooms, air conditioning systems, or for any other application, when oxygen is required. Oxygen can, in this way, be generated much faster and more conveniently than with conventional electrolytic generating equipment.

q. The possibility of absorbing the hydrogen or oxygen by specially selected materials in small containers and where the absorbed gas can be extracted when desired for welding or brazing where it would be inconvenient or impossible to do so with conventional equipment.

r. Making the welding operator entirely independent of any gas suppliers.

s. The generation of cheap gas, up to 6 to 7 times cheaper than normal gas supplies.

t. The design of equipment which gives not only professional welders, but handymen, or people who would like to do welding at home with oxy-welding apparatus, but would do it only occasionally and could not justify the expense associated with conventional gas supplies. Such people cannot justify paying for bottles of gas for a single welding only (having to keep the bottles, paying rent for them to keep them up to two years, to perform the next welding). For this reason, the welding apparatus made possible by the present invention is ideal because it produces gases for welding at the time and in the quantity that is needed.

u. Hydrogen-oxygen welding has the advantage that it does not pollute the atmosphere as does oxy-acetylene welding.

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v. The design of electrolytic cells which are safe to use as well as convenient, which cells may incorporate their own flash-back arrestors as a safety precaution or an equivalent means, to prevent the hazards of explosion or fire.

w. The control of the current which passes through the cells, the temperature of the cell, which is a function of current, the control of the separation of the gases, and the removal from the gases of electrolyte vapours. In this regard there has been designed a special unit with preferably conical electrodes, and a flash-back arrestor. The flash arrestor may be constituted by a pellet of porous material, or a long capillary pipe located between the gas generator and a burner head. The fire hazards associated with a mixture of hydrogen and oxygen cannot be overemphasized and indeed it is probably mainly because of the recognized dangers associated therewith that extreme lengths have been taken to separate the two gases completely until they reach the burner. In accordance with the present invention it has been realized that, contrary to long standing opinions, the gases can be safely mixed together even when being produced and as a result many desirable advantages can be realized.

x. The provision of one or more safety valves adjusted to convenient pressure for releasing excessive pressures in the cell (for example, greater than 30 p.s.i.) which may result, for example, if a current control mechanism fails. The safety valves could be attached to an alarm, for example, to indicate a failure in the current control mechanism or the cut-off switches, etc.

y. Porous material may conveniently be placed in the burner head, so that backfire through the burner into the cell cannot occur.

In summary, the present invention contemplates, as an important feature thereof, a universal welding apparatus capable of being used to perform different types of welding operations based on the utilization of hydrogen and oxygen, making full use of the advantages which can thereby be realized, and equipment which can be made small and portable compared with existing apparatus such as that presently used for gas welding using bulky bottled hydrogen. To generate the fuel, in accordance with the invention a small compact electrolytic cell is made possible in which the only raw material which has to be replenished from time to time is water and which can be used whenever a source of electrical energy is available to supply the necessary amount of hydrogen or hydrogen and oxygen mixture for performing atomic welding or hydrogen-oxygen flame welding. In its simplest form, the gas generating apparatus of the present invention comprises an electrolytic cell adapted to be connected to an energy source, optionally through a step down transformer and rectifier, and having means for connection to a burner, preferably through a flash-back arrestor as a safety precaution.

The apparatus may be combined with a transformer as a single compact unit and for convenience the transformer may be provided with several windings to enable it to be used for auxiliary purposes such as battery charging, electroplating, arc welding or to provide an arc for atomic welding.

It has been found that a single electrolytic cell operating without diaphragms at several hundred amps will generate hydrogen and oxygen at a reasonable rate for small welding and brazing work but for larger work (for

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example, the welding of 10 mm steel plate) the required amperage becomes excessive (typically of the order of 900A or more) when considering the size of conductors and transformer and the problem of heat generation. Accordingly, in one aspect of the invention these problems can be significantly reduced by arranging a plurality of cells in series and using a much smaller current to obtain the same effective gas output. In effect the capacity of a series of cells for a given current input is that of a single cell multiplied by the number of cells. Alternatively the current requirement is reduced by a factor equal to the number of cells — for a given rate of gas production.

Even so a large number of separate cells can be excessively bulky for portable applications and in a further aspect of the invention, therefore, the bulk can be greatly reduced by arranging the cells as a single unit in which a number of electrodes, effectively in series, are arranged adjacent each other in a common electrolytic chamber, the chamber being provided with a gas collection space and an output for connection to, for example, gas burner means. Furthermore, only the end electrodes need be connected to an external source of electrical energy and the arrangement as a whole can be made extremely efficient and compact. Additionally the need for a transformer for most applications can be eliminated by such an arrangement so that the apparatus can be designed to be electrically connected directly to a main electrical supply, through a bridge rectifier if desired. By eliminating the need for a transformer, the gas generating equipment as a whole can be made surprisingly compact, to be well suited for small domestic requirements as well as heavy industrial requirements.

In another important aspect of the invention, there is provided a safety device which monitors the pressure of hydrogen and oxygen being generated and regulates the current flowing through the cell(s) to increase or decrease the rate of gas production depending on the pressure. In one form the device comprises a chamber containing two electrodes, at least one of which is conical, arranged in the chamber (which normally contains a conductive liquid) and the electrodes being connectable in series with one or more electrolytic cells used for oxygen-hydrogen production.

The pressure responsive, current regulating device can be designed as an integral part of the electrolytic cell(s) or can be used as an attachment connectable externally and in series with the gas generating cell(s). The device can also be designed to combine the functions of a current regulating device and a flash-back arrestor, the latter function ensuring that a flame at the burner does not accidentally pass back through the hose lines to the highly explosive mixture in the gas generating cell(s). The device may incorporate a total current cut-out feature or may be used in combination with a cut-out device which fully interrupts the supply of electrical power should the pressure in the cell(s) accidentally exceed a maximum safe value. The current regulating device may also operate to regulate the current passing through the cells in accordance with the temperature to maintain the temperature within a desired range.

Referring to the drawings, FIG. 1 shows schematically a single electrolytic cell 10 operating to produce a mixture of hydrogen and oxygen, which mixture is passed through a flash-back arrestor 11 to a burner 12. The cell 10 contains two plate electrodes 10a and 10b



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immersed in an electrolyte consisting of a solution of KOH in water and connectable through terminals 13 and 14 respectively to a source of a.c. or d.c. electricity. Preferably, d.c. is used as the electrical impedance of the cell, is much lower for d.c. than for a.c. The source of electricity may be a transformer, typically of 300 Amps output rating, connected to the cell through a bridge rectifier. The flash-back arrestor 11 is constituted by a water bath in which gas liberated in the cell 10 passes through a tube 15 into the water bath 11 and thence through a tube 16 to the burner 12. The arrangement is suitable for small welding and brazing work but becomes too bulky for very large work.

FIG. 2 illustrates in vertical cross-section an electrolytic cell 20 which requires a much lower current than the cell illustrated in FIG. 1 for a given current input. The cell 20 comprises what is in effect a series of cells constituted by a plurality of plate electrodes immersed in a solution of KOH in water. For convenience the electrodes are designated as 20a for the two electrodes at the ends and 20b for the intermediate electrodes. The electrodes 20a are connected, via conductors 21 to terminals 22 for connection to an external supply of electricity. The mixture of hydrogen and oxygen which is evolved at the electrodes when an electric current is applied, passes through an outlet opening 23 to a flash-back arrestor and thence to a burner (not shown in FIG. 2). The series of electrodes 20a and 20b are sealingly mounted in a tube 24 of insulating material which is provided with restricted apertures 24a at the top and 24b at the bottom, between each pair of electrodes. The apertures 24a permit gas to escape into the space 25 above the surface of the electrolyte and the apertures 24b permit electrolyte to enter freely into the spaces between each pair of electrodes. By virtue of this arrangement the electrical resistance between any two adjacent electrodes is far less than that between non-adjacent electrodes so that the arrangement is effectively one of a large number of individual cells connected in series. A very compact arrangement is therefore obtained but one which permits a relatively high gas production rate for a reasonably low current input. For example, a structure like that shown, consisting of the equivalent of, for example, 120 cells can generate gas at a current input of 15A (at, for example, 240V) equal to that of a single cell requiring a current input of approximately 1800A. This means in practice that a relatively portable apparatus can be produced which can be connected directly, without a transformer, to most domestic electrical supplies and which can maintain a sufficient rate of gas production for most types of welding work.

An advantage which particularly distinguishes the arrangements disclosed from conventional gas welding apparatus is that the hydrogen and oxygen are automatically produced in substantially the correct proportions to give a neutral flame. No mixing valves are required and even unskilled personnel can produce satisfactory welds without difficulty. In fact indications are that many welds can be produced better than by any other welding process.

FIG. 3 illustrates a pressure responsive safety device 30 operably connected in series (electrically) with an electrolytic hydrogen-oxygen cell 31 for regulating the current passing therethrough in accordance with the gas pressure being generated. The device, or cell 30 comprises a chamber 30' in communication with a reservoir 32 via a passage 33. Two conical electrodes

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34 and 35 are mounted in spaced relation within the chamber and connected in series between a d.c. source (not shown) and the electrolytic cell 31. An electrolytic solution of KOH and water is provided within the chamber, portion of which enters the reservoir 32. When the cell 31 is operating to produce hydrogen and oxygen the pressure of the gas being produced acts on the surface of the electrolyte in the chamber 30' to displace an amount of the electrolyte into the reservoir 32 against back pressure exerted by air trapped in the reservoir, the amount of electrolyte displaced depending on the pressure of the gas in the chamber 30'. At the same time the area of contact between the electrodes and the electrolyte in the cell 30 reduces in proportion to the drop in electrolyte level, causing the electrical resistance of the cell 30 to rise and the current passing therethrough to fall. Should the gas pressure drop the electrolyte level in the cell 30 will rise and the current passing into the cell 31 will also rise. Thus the cell 30 operates to regulate the rate of gas production in accordance with the pressure produced and prevents excess gas pressure to build up in the cell 31.

FIG. 4 illustrates an alternative form of safety device which is operable to make or break the connection between an electrolytic hydrogen-oxygen cell (not shown in FIG. 4) and an electric current source. The device comprises a cylindrical container 40 in fluid communication with a liquid reservoir 41 via a passage-way 42, and a quantity of mercury 42' contained in the container and reservoir. Two electrodes 43 and 44 are disposed one above the other in the container 40 and are normally immersed in the mercury with a conductive path thereby formed between them. The container is connected electrically in series with an electrolytic cell (or cells) and in gaseous communication therewith through a hose 45. An increase in gas pressure resulting from generation of gases by the electrolytic cell(s) causes the mercury to be displaced towards the reservoir and the mercury level in the container 40 to fall. When the pressure exceeds a predetermined level the mercury level falls below that of the electrode 43 and electrical connection between the two electrodes is broken. The electrical connection is again restored when the gas pressure falls. A non-inflammable liquid, such as silicone oil or freon is provided on top of the mercury to ensure that any arc which may be generated between the electrode 43 and the mercury is totally isolated from the gases above the liquids.

FIG. 5 shows schematically an arrangement whereby an exceedingly hot flame can be produced using the gaseous mixture generated electrolytically by the apparatus previously described. In this arrangement a mixture of hydrogen and oxygen, preferably in stoichiometrical proportion, is passed via a line 50 between a pair of tungsten electrodes 51 to produce molecular dissociation of the hydrogen and the oxygen and a very hot flame 52. It can be appreciated that whereas in an atomic hydrogen flame a significant temperature rise is obtained by striking an arc in the hydrogen, an even greater temperature rise can be realized by striking the arc between the oxygen as well since the dissociation energy of molecular oxygen is of the same order of magnitude as that of molecular hydrogen.

FIG. 6 illustrates an arrangement for the magnetic separation of oxygen from a mixture of oxygen and hydrogen, whereby the oxygen can be used for flame cutting. The apparatus consists of a chamber 60 con-

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taining a magnet 61 and is located in a conduit 62. A mixture of hydrogen and oxygen is passed through the conduit and around the magnet 61. The diamagnetic oxygen is diverted by the magnetic field into a transverse passageway 63 to a central conduit (not shown) leading from this passageway and thence to a flame-cutting head. The paramagnetic hydrogen continues along the conduit, past the magnet and can be allowed to escape or can be collected, as desired. If the magnet is an electromagnet it can be turned off when hydrogen and oxygen is required as a mixture, and in that case the downstream side of the conduit 62 can be closed off to prevent the loss of gas.

FIG. 7 illustrates a complete oxy-hydrogen generator and welding apparatus comprising a gas generator 70, a current regulating cell 71 and a power supply 72. The construction of the electrodes 73 of the generator 70 and 74 of the cell 71 are identical with those illustrated in FIGS. 2 and 3 respectively. In this arrangement, however, the gas generator 70 and cell 71 are combined as an integrated unit and as such has some features not found in the arrangements shown in FIGS. 2 and 3. In particular the chamber 75 of the generator 70 and the chamber 76 of the current regulator cell 71 are separated by two partitions 77 and 78 defining between them a passageway communicating between the two chambers. The respective electrodes of the cell 71 and a generator 70 are connected electrically in series with the power supply.

Gas produced by electrolysis in the chamber 75 rises into the space in the chamber above the electrodes 73, passes down the passageway between the partitions 77 and 78, bubbles through the electrolyte in the chamber 76 and thence passes through an outlet opening 79 to a burner 80. An air trap reservoir 81 is formed integrally with the cell 71 and is in liquid communication therewith through an opening between the bottom of the reservoir and the cell. When the pressure of the gas generated by the generator 70 rises, this pressure causes the electrolyte in the chamber 76 to be displaced into the reservoir 81 resulting in a reduction of the current being passed to the generator 70 by the mechanism previously described in relation to FIG. 3 of the drawings. In this way the cell 71 effectively monitors the gas pressure and regulates the current to maintain an approximately constant pressure. To ensure against the possibility that the pressure should accidentally exceed a predetermined maximum safe value, a spring-loaded safety pressure valve 82 is provided at the top of the reservoir 81 to release the excess pressure into the atmosphere.

The burner 80 is provided with a flash-back arrestor in the form of a porous ceramic pellet 83 located in the gas flow path between the handle part 84 of the burner and the burner tip 85. The flash-back arrestor acts by quenching any flame blowing back into the burner before the flame has a chance to reach the hose 86 connecting the burner with the gas generator.

The power supply is of the universal type, that is, it is provided with a transformer 87 connectable to an alternating current electrical supply and provided with a number of electrical outlets for various purposes. One winding of the transformer is connected to a bridge rectifier which provides the d.c. current for the gas generator. Another winding is used for arc welding or can be used to supply an arc for atomic oxy-hydrogen welding. It will be appreciated that the transformer is optional and that the generator can be connected di-

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rectly to the mains. In fact the bridge rectifier is not essential either and can be omitted if desired.

In the operation of apparatus of the type described it is often required to conveniently change between neutral and oxidizing flames, for example when changing from a welding operation to a cutting operation and the present invention makes provision for the variation of these functions. Briefly, in accordance with the present invention, apparatus for either oxy-hydrogen welding or cutting may comprise a first electrolytic generator for generating hydrogen and oxygen by the electrolysis of water in substantially stoichiometric proportions to produce a neutral flame and a further electrolytic generator from which hydrogen and oxygen are separately delivered, which means for adding either the hydrogen from this further cell, or the oxygen from the further generator to the gas mixture obtained from the first generator. This arrangement results in a most efficient combination of functions when a neutral flame or other is required. The hydrogen gas produced by the further generator, when added to the flame mixture, burns with atmospheric oxygen thereby producing a reducing flame. When an oxidizing flame is required, the additional hydrogen is cut off and the oxygen produced by the further generator is added to the flame mixture. It will be appreciated that various designs can be employed for either generator, for example, they may be completely independent or they may share a common electrolyte. The further gas generator can also, in practice, be made somewhat smaller than the other generator since it does not have to produce the bulk of the gas required.

It has been found that welding with hydrogen and oxygen in an exact 2 to 1 ratio (as when the gases are produced electrolytically) results in a particularly clean, oxide free welded surface and a strong welded joint. For the same quality welding to be produced by conventional gas welding technique substantially greater skill is required and, in the case of conventional hydrogen welding, for example, good welded joints are obtained only with great difficulty due to the extreme difficulty in obtaining and maintaining a neutral flame. With the method of the present invention there is no difficulty in obtaining a neutral flame, and hence the ease with which high quality welds can be obtained.

Finally, it can sometimes be convenient to store hydrogen and/or oxygen, generated electrolytically in a specially designed container, or to slowly accumulate these gases and then, when required, using the accumulated stored gas for extra heavy work for a short time. It is quite hazardous to pressurize a mixture of hydrogen and oxygen under very high pressures, of course, but it is possible, in accordance with one aspect of the invention, to store a useful amount of gas in a relatively small volume at low pressures and this can be done by using a highly gas absorbent metal in the storage container. The metal palladium, for example, can absorb up to 900 times its own volume of hydrogen and can be used with advantage for this application. In fact useful amounts of hydrogen, for small scale brazing work can readily be stored in a small hand held container, containing a gas absorbent material.

I claim:

1. Apparatus for generating a supply of hydrogen gas and oxygen gas in proportion to consumption of said gases comprising,

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- a. an electrolytic cell means for electrolytic generation of said gases, said cell being enclosed to entrap said generated gases,
- b. a gas outlet carried by said cell to allow a portion of said generated gases to discharge from said cell,
- c. a source of electrical power connected to said cell by a suitable circuit, and
- d. an electrical power regulating means for controlling the amount of power to said cell including:
  - a first chamber having a selected cross-sectional area and an upper and lower inlet, said upper inlet connected with said gas outlet of said cell,
  - a second chamber having a selected cross-sectional area at least one half less than that of said first chamber and a lower inlet, said inlet connected to said lower inlet of said first chamber by a suitable passage,
  - a first and second inverted conically-shaped and concentrically aligned resistant electrode carried in a vertical relationship in said first chamber, said electrodes connected in said circuit between said power source and said cell, and
  - a quantity of electrolytic solution carried in said chambers to partially fill said chambers and interface with said electrodes to close said circuit,
 wherein an increase in the pressure of said entrapped gases depresses the level of said electrolytic solution in said first chamber to cause an increase in resistance of said electrodes thereby reducing the amount of power to said cell.
2. Apparatus for generating a supply of hydrogen and oxygen gases comprising,
  - a. an electrolytic cell means for electrolytic generation of said gases, said cell being enclosed to entrap said generated gases,
  - b. a gas outlet carried by said cell to allow a portion of said generated gases to discharge from said cell,
  - c. a source of electrical power connected to said cell by a suitable circuit, and
  - d. an electrical power regulating means including,
    - a first chamber having a selected cross-sectional area and an upper and lower inlet, said upper inlet connected to said outlet of said cell,
    - a second circular chamber having a preselected cross-sectional area, said area of said second chamber being at least one-half that of said first chamber, and a lower inlet, said inlet connected to said lower inlet of said first chamber by a passage,
    - a quantity of electrolytic solution carried in said chamber to partially fill said chambers,
    - a quantity of non-conductive liquid having a specific gravity less than said electrolytic solution carried in said first chamber above said electrolytic solution, and
    - a first and second electrode carried by said first chamber in a vertical relationship and extending inwardly therein to interface with said electrolyte solution, said electrodes connected in said circuit between said power source and said cell to close said circuit,
 wherein a sufficient increase in pressure of said entrapped gases depresses the level of said non-con-

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- ductive liquid and said electrolyte to interface said upper electrode with said non-conductive material whereby said circuit is opened.
3. An apparatus according to claim 2 and further characterized by said apparatus comprising,
  - a flash-back arrestor in the form of an elongated capillary having a first end connected to said outlet of said cell and a second end connected to a gas consumption means.
4. An apparatus according to claim 2 and further characterized by said apparatus comprising,
  - a flash-back arrestor in the form of an elongated capillary having a first end connected to said cell outlet and a second end connected to a gas consumption means.
5. System for generating a supply of hydrogen gas and oxygen gas in proportion to a consumption of said gases and protecting said system comprising:
  - a. an electrolytic cell means for electrolytically generating said gases, said cell being enclosed to entrap said generated gases,
  - b. a source of electrical power connected to said cell by a suitable circuit, and
  - c. a gas outlet means to allow a discharge of said gases and protect said cell from a flash-back and provide regulation of said gas generation further including,
    - a first vertical chamber having a top inlet connected with said cell and a bottom outlet,
    - a second vertical chamber having a substantially greater cross-sectional area than said first chamber, said second chamber having a top outlet for discharging said gas to a gas consumption means, and a first and second bottom inlet, said first inlet connected to said bottom inlet of said first chamber by a horizontal passage,
    - a third vertical chamber having a bottom inlet connected to said second bottom inlet of said second chamber, said third chamber having a cross-sectional area greater than said first chamber and less than said second chamber,
    - a quantity of electrolytic solution carried in said first, second and third chamber to partially fill said chambers,
    - a first and second inverted, conically-shaped resistant electrodes concentrically aligned and carried by said second chamber in a vertical relationship, said electrodes connected in said circuit to close said circuit when in contact with said electrolyte,
 wherein an increase in pressure in said second chamber depresses the level of said electrolyte to decrease the generation of said gases by increasing resistance in said circuit by increasing exposed portions of said resistant electrodes, said electrolyte acting as a protective barrier between said gas consumption means and said cell.
6. An apparatus according to claim 5 and further characterized by said apparatus comprising,
  - a flash-back arrestor in the form of an elongated capillary having a first end connected to said cell outlet and a second end connected to a gas consumption means.

\* \* \* \* \*

## AUTOMOBILE DRIVEN BY HYDROGEN FUEL

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**Inventor:** NORO KATSUHIKO; OKADA HIROSHI; HARA KOUJI

**Applicant:** KYODO SANZO

**Classification:**

- international: **F02M21/02; F02D19/02; F02M21/02; F02D19/00; (IPC1-7): F02M21/02**

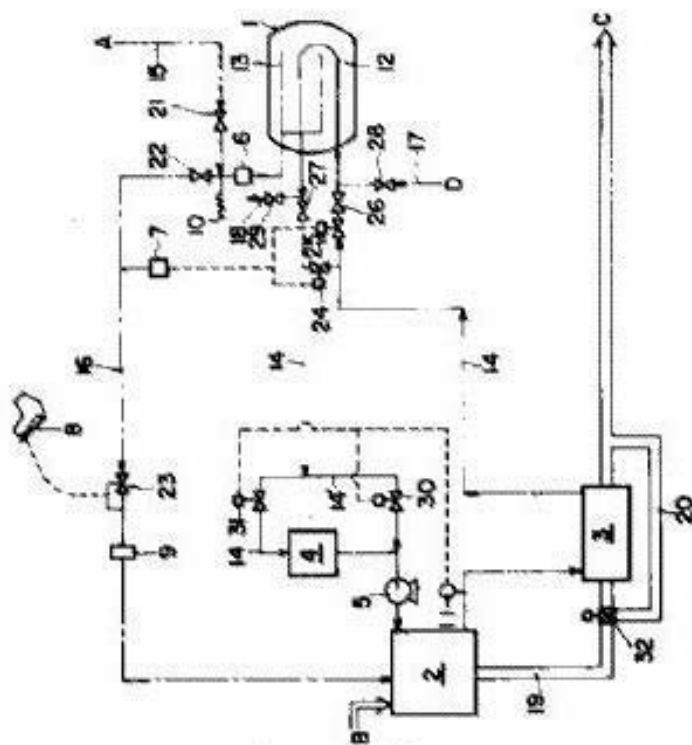
- European: **F02D19/02**

**Application number:** JP19820067988 19820421

**Priority number(s):** JP19820067988 19820421

### Abstract of JP58183853

**PURPOSE:** To simplify the structure of a fuel supply system, by providing a pressure-reducing valve operated by an accelerator pedal at an intermediate part of a fuel supply pipe which is extended from a hydrogen fuel utilizing a metal hydride absorbing hydrogen gas at a low pressure as a hydrogen occlusion medium to a hydrogen intake valve of an engine. **CONSTITUTION:** A hydrogen fuel tank 1 consists of a low withstand pressure vessel utilizing, for instance, a hydride of a metal such as Fe, Ti as a hydrogen occlusion medium, and heated water carried via a cooling water circulating passage 14 and passed through the exhaust pipe of an engine 2 and external cooling water carried via a cooling-water supply pipe 17 are supplied to the tank 1. The supply rates of the heated water and the external cooling water are controlled respectively by pressure regulating valves 24, 25 which are opened and closed in response to the pressure of hydrogen gas in a pipe 16. Further, a hydrogen supply pipe 13 is connected to a hydrogen gas supply source A via a feed pipe 15 having a filter 6 and a hydrogen feed valve 21 so that the hydrogen gas can be supplied to a hydrogen intake valve of the engine 2 via a pressure-reducing valve 23 operated by an accelerator pedal 8 and a hydrogen safety device 9.



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